United States Department of Agriculture

Forest Service

Bibliographies and Literature of Agriculture 126

Washington, D.C.

February 1994

Density, Modulus of Elasticity, Creep, and Durability of Hardboard

A Bibliography

Abstract

The references in this literature review cover four areas related to hardboard: (1) density or specific gravity, (2) modulus of elasticity (MOE) and stiffness, (3) dimensional stability and water resistance, and (4) weathering and accelerated aging. The purpose of the literature search was to provide a starting point for discussing directions for future research and ways to improve the performance of hardboard products. The annotations encapsulate important research results. The majority of the references are grouped first by research area and then by type of hardboard fiber-mat forming process (dry, wet, or dry and wet processes). The final section of the publication includes references on North American hardboard standards and test methods for both dry and wet processes. The study on which this publication was based was funded by the American Hardboard Association, Palatine, Illinois; U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, Wisconsin; and Illinois Agricultural Experiment Station, University of Illinois, Urbana, Illinois.

Acknowledgment

The compilation of this comprehensive bibliography would not have been possible without the assistance of many individuals. Particular thanks are given to J. Dobbin McNatt and Gary C. Myers, U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, Wisconsin, and Damon H. Lipinski, Research Assistant, Department of Forestry, University of Illinois, Urbana–Champaign, for their reference search, help in locating original sources, and review.

Thanks are due to the American Hardboard Association (AHA), Palatine, Illinois, for the funding that enabled the authors to undertake this study. Thanks are also due to C. Curtis Peterson and Louis E. Wagner of the AHA for their assistance.

February 1994

Youngquist, John A.; Scharmer, Roger C.; Chow, Poo; Bao, Zhao–Zhen. 1994. Density, Modulus of Elasticity, Creep, and Durability of Hardboard: A Bibliography. Bibliographies and Literature of Agriculture 126. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 41 p.

The Forest Products Laboratory is maintained in cooperation with the University of Wisconsin.

United States
Department of
Agriculture

Forest Service

Bibliographies
and Literature
of Agriculture 126

Washington, D.C.

February 1994

Density, Modulus of Elasticity, Creep, and Durability of Hardboard

A Bibliography

John A. Youngquist, Project Group Leader
Roger C. Scharmer, Library Director

U.S. Department of Agriculture
Forest Service, Forest Products Laboratory
One Gifford Pinchot Drive
Madison, WI 53705–2398

Poo Chow, Professor
Zhao–Zhen Bao, Research Assistant

Department of Forestry
University of Illinois, W–503 Turner Hall
1102 South Goodwin Avenue
Urbana, IL 61801–3681

Contents

Introduction

The literature references in this report are the results of a study by the Forest Products Laboratory of the USDA Forest Service and the Department of Forestry at the University of Illinois, Urbana–Champaign for the American Hardboard Association. The publications were authored by 277 research scientists and organizations from 1948 to 1992. About 80 percent of the research was conducted in the past two decades. Of the 287 reports and patents, 219 were published between 1971 and 1991. Only 22 reports were published between 1948 and 1960, and 46 reports were published between 1961 and 1970. Table 1 lists the number of reports by year of publication. The largest number of citations are from the United States (132), followed by Russia (40), Germany (36), and Japan (22) (Table 2). Because many of the original publications were unavailable, the literature search was based primarily on research published in English.

Table 1—References by publication year

Year	Reference (no.)	Year	Reference (no.)
1948	2	1971	3
1949	0	1972	6
1950	2	1973	15
1951	2	1974	13
1952	0	1975	10
1953	0	1976	16
1954	4	1977	11
1955	1	1978	14
1956	3	1979	12
1957	1	1980	7
1958	4		
1959	0	1981	14
1960	3	1982	7
		1983	14
1961	2	1984	8
1962	0	1985	12
1963	2	1986	12
1964	4	1987	14
1965	2	1988	11
1966	5	1989	7
1967	5		
1968	11	1990	7
1969	11	1991	5
1970	4	1992	1
Total: 287			

Table 2—Sources of references

Region and reference source	Reference (no.)
United States (USA)	
USDA Forest Service, Forest Products Laboratory Report	13
Forest Products Journal	59
Wood Science, Wood and Fiber (journals)	8
Forest industry	1
Wood and wood products groups	1
American Hardboard Association (AHA)	3
American Society for Testing and Materials (ASTM)	2
American Plywood Association (APA)	1
Technical Association of Pulp and Paper Industries (TAPPI)	4
International Union of Forestry Research Organization	1
Michigan State Agricultural Experiment Station	6
Oregon State Experiment Station	3
Ph.D. thesis	4
Environmental Protection Agency (EPA)	1
Safety of Automotive Engineering (SAE)	2
Washington State University Particleboard Proceedings	2
Furniture design and manufacturing	1
Journals on wood finishes	4
Food and Agriculture Organization, United Nation (FAO)	1
Book	3
Patent	12
Subtotal	132
Russia	
Paper	31
Patent	9
Subtotal	40
Japan	
Paper	17
Patent	5
Subtotal	22
Germany	
Holz als Roh- und Werkstoff	8
Holztechnologie	9
Holzforschung and Holzverwertung	11
Papier	1
Wood Science and Technology and other Journals	6
Patent (East)	1
Subtotal	36
Sweden	9
Belgium	8
Australia	7
Great Britain	7
Canada	6
Bulgaria	4
India	3
China	2
Taiwan (ROC)	2
Bangladesh	1
Egypt	1
Finland	1
Korea	1
New Zealand	1
Romania (Patent)	1
South Africa	1
Spain (Atipca)	1
Yugoslavia	1

Scope of Research

Most studies in the literature search deal with hardboard stiffness, creep properties, and dimensional stability. Table 3 shows the number of reports and patents by hardboard forming process. Researchers tried to find effective ways to increase modulus of elasticity (MOE), improve water resistance, and reduce dimensional changes caused by environmental variations. Moisture content and density were found to be significant factors affecting board properties. Additives such as paraffin wax, sizing chemicals, and different resins were added to wood fibers to make the hardboard stronger and more stable. Some researchers acetylated the fibers to improve dimensional stability of the board. Results of these studies showed that the moisture sorption and thickness swelling of acetylated board was reduced compared to that of untreated boards. Steam pretreatment on fibers was also proven to be an effective way of increasing water resistance and dimensional stability as well as improving the strength of the boards.

A few studies evaluated the effects of hot pressing temperature on board properties. Results indicated that MOE increased with increasing temperature (within a certain temperature range). Fiber orientation enhanced most board properties. The MOE and dimensional stability increased in the direction of fiber orientation. Electrical alignment was also investigated; hardboard was proven to have substantially increased directional strength and dimensional stability. The performance of hardboard webbed I-beams under different loading conditions was investigated. The effects of different variables on the behavior and durability of the beams were discussed.

Weathering and accelerated aging tests of hardboards were conducted to examine changes in various board properties and the durability of boards under severe environmental changes. Test results were compared to the standard American Society for Testing and Materials (ASTM) six-cycle accelerated aging test and other time-saving aging tests.

This literature indicates that additional research is needed to obtain information on how moisture exposure and outdoor weathering affect the performance of hardboard siding. There is also a need to set allowable design stress values and to establish performance standards for structural hardboard products.

Table 3—Categoriziation of references by topic and forming process

	Report (no.)			Patent (no.)		
Topic	Dry	Wet	Dry and wet	Dry	Wet	Dry and wet
Density	11	9	6	-	-	-
MOE						
Modulus	19	26	22	3	2	6
Creep	4	8	14	-	-	-
Subtotal	23	34	36	3	2	6
Stability and water resistance	23	51	25	7	14	4
Weathering and aging	3	11	13	-	-	-
Standards and test methods	-	-	6	-	-	-
Total	60	105	86	10	16	10

Organization of Literature Review

The references are grouped into five sections: four are based on areas of research related to hardboard and the fifth is based on North American hardboard standards and test methods. Within each section, the references are categorized by hardboard fiber-mat forming process: wet, dry, and wet and dry processes. The summaries encapsulate important research results.

The full entry for each reference appears only once, under the section relevant to the main hardboard forming process addressed by the publication. If the publication also addresses other topics, it is cross-referenced to other sections. For example, because the report by Steinmetz and Polley (41) focuses on modulus of elasticity and stiffness, its full entry appears in the section on Modulus of Elasticity and Creep Properties, under the subheadings Research and Dry Process. Because this publication also reports the dimensional stability of hardboard, it is cross-referenced at the end of the section on Dimensional Stability and Water Resistance, Research, Dry Process.

Method of Literature Search

A comprehensive literature search was conducted by Roger Scharmer of the Forest Products Laboratory. The following data bases were accessed from the DIALOG search service: AGRICOLA, AGRIS INTERNATIONAL, CA SEARCH, CAB ABSTRACTS, CLAIMS/U.S. PATENT ASTRACTS, COMPENDEX PLUS, DISSERTATION ABSTRACTS ONLINE, NTIS, PAPERCHEM, and DERWENT WORLD PATENT INDEX. These data bases included records through April 1992; DISSERTATION ABSTRACTS goes back to 1861, the patent data bases go back to 1950 and 1963, and the other data bases go back to about 1967. Citations were also obtained from the Forest Products Society's FOREST data base and from the Forest Service's FS INFO data base. This analysis yielded a total of 1,552 citations, which were pared to the 287 applicable references reported here.

With some variations among the data bases, the keywords and search strategy included the following:

"fib??board?" or "hardboard?" or
"fib??()board?" or "hard()board?"
and
"dry process" or "wet process" or
"thickness swelling" or "linear expansion" or
"durability" or "dimensional stability" or
"water resistance" or "buckling" or
"warpage" or "water absorption" or
"creep" or "mass" or
"physical properties" or "mechanical properties" or
"aging" or "ageing" or "weathering" or
"density" or "weight" or
"elastic strength" or "stiffness" or
"moisture resistance" or
"modulus(1w)elasticity" or "MOE" or
"strength" or "specific gravity" or
"effects(1n)(water or moisture or snow or rain)" or "permeability" or "warping" or "hysteresis"

Density and Specific Gravity Research

Dry Process (1–11)

1. Brooks, S.H.W. 1990. Air lay nonwoven moldable mat process and products produced by using this mat process. Proceedings: TAPPI; 1990 Nonwoven conference: 87–108.

Summary: Dry process molded fiberboard with a specific gravity ≤1.25 or 1.33 was used as the core of a molded car part using 6 percent phenyl formaldehyde resin. The phenol formaldehyde resin content of the surface was 20 percent. Spinner glass was used as the surface layers. Boards bending modulus of elasticity, tensile stress, 2-h boil thickness swell, and weight gain values were 1,310 x 10^3 lb/in^2 (9.0 MPa), 7,000 x 10^3lb/in^2 (48.3 MPa), 49 percent, and 15.9 percent, respectively. All mats were made using the air-lay process.

2. Chow, P.; Hanson, R.C. 1980. Shelling ratio and core density effects on stiffness, ultimate strength, and toughness of veneered-hardboard beams. Forest Products Journal. 30(1): 37–40.

Summary: At shelling ratio of ≥0.262, stiffness of veneered, dry-process hardboard core composite panels approached that of red oak lumber. As a function of dry-process hardboard core density, shelling ratio, and their interaction, all modulus of elasticity, modulus of rupture, and toughness values could be described by three regression equations. The interaction of hardboard core density and shelling ratio affected modulus of elasticity and toughness but not modulus of rupture.

3. Henkel, M. 1969. Determination of the density profiles of wood-particle boards and fiberboards using x-ray radiation. Holztechnologie. 10(2): 93–96. (Ger.; Russ.; Engl. sum.).

Summary: Radiation penetrating the boards was determined either directly (ionization chamber) or photographically and was used as a measure of board density.

4. Laufenberg, T.L. 1986. Using gamma radiation to measure density gradients in reconstituted wood products. Forest Products Journal. 36(2): 59–62.

Summary: Use of gamma radiation for measurement of wood density and density gradients for reconstituted wood products (1) is faster and offers better resolution than traditional planing or sanding and weighing methods; (2) is not significantly affected by the normal ranges of resin content,

changes in wood species, and ambient moisture conditions; (3) offers a nondestructive test method which may be used for in-plant quality control, pressing control, and research evaluation of composite wood products.

5. Maloney, T.M. 1977. Modern particleboard and dry-process fiberboard manufacturing. San Francisco, CA: Miller Freeman Publication. 672 p.

Summary: This book describes the effects of various manufacturing processes on properties of dry-process fiberboard and particleboard.

6. Nearn, W.T.; Bassett, K. 1968. X-ray determination and use of surface-to-surface density profile in fiberboard. Forest Products Journal. 18(1): 73–74.

Summary: X-ray radiography is shown to be a useful tool for determining the density profile in fiberboard and wood particleboard. The technique appears promising as a means of maintaining quality control.

7. Osawa, K.; Moriyama, M.; Endo, H.; Takahashi, H. 1975. The relation between hygroscopicity and physical properties of dry-process fiberboards. Journal of the Hokkaido Forest Products Research Institute. 3: 9–12. (Jap.; Engl. sum.).

Summary: The relation between equilibrium moisture content, thickness swelling caused by absorption of water, and changes in the physical properties of the boards was investigated. A correlation was found between decrease in specific gravity with thickness swelling and decrease in modulus of rupture of the boards.

8. Stern, R.K. 1979. Performance of pallets with hardboard decks of varied density. Res. Pap. 335 (12 p.); 340 (9 p.). Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Summary: A number of hardboard panels were made for the study and used to make top decks of 40 test pallets. The board densities were 27, 39, 42, and 45 lb/ft^3 (432, 624, 672, and 720 kg/m^3) at 7 percent moisture condition. The results indicated that notched stringer pallets of the common 48- by 40-in. (18.9- by 15.5-cm) size made with hardboard decks required medium density hardboard of a thickness >3/4 in. (19 mm) to equal or exceed the performance of similar lumber pallets with decks of nominal 1-in. (standard 1.27-cm) red oak.

9. Takahashi, H.; Moriyama, M.; Osawa, K.; Endo, H. 1979. Warp of boards and manufacturing conditions of dry fiberboards. Journal of Hokkaido Forest Products Research Institute. 332: 6–10. (Jap. sum.).

Summary: The influence of manufacturing variables on the warpage of dry-process fiberboards was investigated. Warping tendency was found to increase with increase in specific gravity but to decrease with increase in fiber size, resin addition, and board thickness.

10. Turner, H.D.; Kern, J.D. 1950. Relation of several formation variables to properties of phenolic-resin-bonded wood-waste hardboard. Rep. 1786. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Summary: The effects of resin content, particle size, and molding pressure upon specific gravity, strength, and water absorption of hardboard products were studied. Bending strength was found to vary with specific gravity or density, whereas water absorption varied inversely with increasing density.

11. Woodson, G.E. 1977. Density profile and fiber alignment in the hardwood fiberboard. Forest Products Journal. 27(8): 29–34.

Summary: Density profile and fiber orientation were evaluated for their effects on selected mechanical properties of fiberboard. Bending modulus of elasticity was predicted from density profiles established by x-ray radiography. Results indicated that oriented fiberboard has mechanical properties superior to boards of equal density but with randomly placed fiber.

Wet Process (12–20)

12. Colov, V.H.; Karag'ozov, T. 1983. The significance of press factors for the properties of high density fiberboards. Holztechnologie. 24(1): 19–22.

Summary: Specific gravity, thickness swelling, water absorption, and bending stress were significantly affected by press temperature, pressure, and press time. The linear regression equations were developed for the high density hardboard.

13. Frashour, R.G.; Nixon, G.D. 1956. Hardboard from extracted juniper chips. Forest Products Journal. 6(2): 73–76.

Summary: Chips from western juniper that had been steam-distilled to recover volatile oil were ground in an attrition mill and then made into hardboard. Additives and higher pressing temperatures increased specific gravity values.

14. Law, K.N.; Balatinecz, J.; Garceau, J. 1975. Density-strength development in oriented and

random fiber sheets. Forest Products Journal. 25(6): 28–29.

Summary: Wet-felted oriented fiber sheets developed a much higher tensile strength in the direction of fiber orientation than did conventional random sheets. The increase in tensile strength from 50 lb/in^2 (0.344 MPa) sheet pressure to 300 lb/in^2 (2.07 MPa) was 122 percent for the oriented sheets and 100 percent for the random sheets. The oriented sheets also developed a higher density than the random ones.

15. McCollum, M.P. 1986. Predicting modulus of rupture for hardboard siding substrate using hot-press operating conditions. Forest Products Journal. 36(5): 36–37.

Summary: A system of three interrelated equations was used to predict the density, core temperature, and bending properties of Southern Pine hardboard.

16. McMillin, C.W. 1968. Fiberboards from loblolly pine refiner groundwood: Effects of wood characteristics and board density. Forest Products Journal. 18(8): 51–59.

Summary: Most properties were improved by using fiber refined from dense wood containing a relatively low proportion of summerwood. Fiber prepared from corewood of high unexpected specific gravity yielded boards of superior strength, while fiber refined from slabs and edgings of low density yielded boards of inferior strength.

17. Ota, M.; Mataki, Y.; Kawabe, J. 1973. On the relation between mechanical defibrating condition and the properties of S1S hardboard, manufactured from various hardwoods of the Kyushu district. Ota, M.; Kawabe, J.: Studies on the strength properties of S1S hardboard. Part 1. Effect of mesh number of wire netting and hot pressing time. Bulletin of the Kyushu University Forests 1973. 47: 311–317. (Jap.; Engl. sum.).

Summary: For optimum board strength, a defibrating time of 2.0 to 2.5 min was required for lighter species and a defibrating time of 3.0 to 4.0 min for heavier species. Defibration for periods longer than stated resulted in a reduction in board strength.

18. Spalt, H.A.; Sutton, R.F. 1968. Buckling of thin surfacing materials due to restrained hygroexpansion. Forest Products Journal. 18(4): 53–57.

Summary: Wood-based surfacing materials were evaluated for buckling through the use of column mechanics. Axial compression loads were imposed mechanically and by directly restraining hygroexpansion. Buckling was found to be related to the thickness of the material and the length of the unsupported span but not to the specific gravity and elastic modulus.

19. Takamura, N. 1971. Measurement of density variations in fiberboard structure by photodensitometric technique. Journal of Japanese Wood Research Society. 17(9): 415–418. (Jap.; Engl. sum.).

Summary: Automatic fiberboard density was determined by analyzing x-ray photos of the boards in an automatic recording double-beam microdensitometer. The density profiles of hardboard and medium-density insulation board cross sections were precisely reproducible within density variations of 0.4 to 0.5.

20. Walters, C.S. 1974. Assaying the caliper and specific gravity of embossed hardboard products. Wood and Fiber. 6(2): 164–171.

Summary: Three 4- by 16-ft (1.2- by 4.9-m) panels of two types of embossed hardboard (bayside and barkridge) were assayed for variation in thickness and specific gravity. A needle-type caliper was found to give more precise measurement of thickness than did ball- or plate-type contact points. Specific gravity was highly correlated with edge thickness. The scheme specified in ASTM D 1037 would not be satisfactory for assaying the density of embossed hardboard panels.

(Also see references 57, 61, 164, 170, and 201.)

Dry and Wet Processes (21–26)

21. Bennett, G.A. 1969. An investigation of some properties of medium hardboard. Timberlab Papers 4. [City unknown], England: Prince Risborough Laboratory. 22 p.

Summary: The results of the investigation provided for greater discrimination between boards and the introduction of a classification system that defines classes for various properties of boards made with fresh chips.

22. Boehme, C. 1980. Investigations on the connection between density, internal bonding, bending strength, and Young's modulus for different types of wood fiberboards. Holzforschung und Holzverwertung. 32(5): 109–113. (Ger. sum.).

Summary: Boards of normal hardness and density >562 lb/ft^3 (>900 kg/m^3), medium hardness and density <562 lb/ft^3 (<900 kg/m^3), and extra hardness were tested. The bonding properties were related to density, but the Z-tensile strength was related only to those boards of the first group that were <4 mm thick.

23. Dube, H.; Kehr, E. 1983. Properties of industrially-manufactured fiberboards and particleboards. Holztechnologie. 24(4): 206–215. (Ger.; Engl.; Russ. sum.).

Summary: Wet- and dry-process hardboards, calender-pressed fiberboard and thin particleboard, and flat-pressed thin particleboard of different thicknesses were tested. Board density profiles (across board cross sections) were shown as well. Relations were analyzed between bending strength and modulus of elasticity, board density and bending strength, and board density and modulus of elasticity. No relation was found between internal bond and density.

24. Food and Agriculture Organization (FAO). 1958. Fiberboard and particleboard. Rome, Italy: Food and Agriculture Organization of the United Nations. 192 p.

Summary: Report of an international consultation on the technology and production of wood insulation board, hardboard, and particleboard. Density classifications for hardboard were specified.

25. Ostman, B.; Back, E. 1958. Publications of fiberboards. 1946–1984. med nyckelordsregister. STFI–middelande serie D nr. 241. Stockholm, Sweden: Svenska Traforskningsinstitutet. 57 p.

Summary: This report compiled all studies related to hardboard and insulating wallboard products completed in Sweden between 1946 and 1984.

26. Suchsland, O.; Woodson, G.E.; McMillin, C.W. 1983. Effect of hardboard process variables on fiber bonding. Forest Products Journal. 33(4): 58–64.

Summary: The S2S boards had superior mechanical properties, higher internal bond values, and greater linear expansion than S1S boards. Modulus of elasticity and bending strength were sensitive to and in close correlation with board density, especially for the S2S dry-formed boards. Both wet- and dry-formed S1S boards exhibited similar properties.

(Also see references 109, 125, 126, 127, 128, 129, and 217.)

Modulus of Elasticity and Creep Properties

Research

Dry Process (27–49)

27. Chow, P. 1979. Deflection in bending of birch-veneered wood-base composite shelving panels. Forest Products Journal. 29(12): 39–40.

Summary: This report presents comparative bending test data on the average values of creep deflection for 14 selected commercial birch-veneered composite panels about 0.7 in. (1.9 cm), 7.9 in. (20 cm), and 33.9 in. (86 cm) for thickness, width, and length, respectively. Test results indicate that the fiberboard core with face and back birch veneer thickness 0.04 in. (>1.0 mm) proved to be an acceptable and reasonable substitute for present 0.75-in.- (19-mm-) thick birch-veneer-faced Douglas-fir core plywood shelves.

28. Chow, P.; Hanson, R.C. 1979. Effects of load level, core density, and shelling ratio on creep behavior of hardboard composites. Wood and Fiber. 11(1): 57–65.

Summary: Creep deflections of all composite panels were affected by load, core density, and shelling ratio; the deflections were well-described by a power-law function. Three multivariable regression models were developed to predict the initial, total, and irrecoverable creep deflections as a function of shelling ratio, load, and fiberboard core density. Their correlation coefficients were 0.96, 0.87, and 0.85, respectively.

29. Chow, P.; Redmond, M.R. 1981. Humidity and temperature effects on MOR and MOE of hard maple-veneered medium density fiberboard. Forest Products Journal. 31(6): 54–58.

Summary: Bending modulus of elasticity of maple veneered fiberboard composites was evaluated at all combinations of 50, 64, 78, and 92 percent relative humidity, and at 50°F (10°C), 75°F (24°C), and 100°F (38°C) conditions. Regression models were developed to predict modulus of elasticity values of all panels. The effects of relative humidity on modulus of elasticity were greater than the effects of temperature. The effects of high temperature were greater at high relative humidity levels than those at lower relative humidity levels.

30. Chow, P. 1982. Bending creep behavior of *Acer saccharum* Marsh veneered medium-density fiberboard composite. Wood Science and Technology. 16(3): 203–213.

Summary: The effects of shell ratio on initial elastic deformation, irrecoverable creep, and total creep deformations of 9- by 23-in. (229- by 584-mm) sugar maple-veneered medium-density fiberboard panels 0.63 in. (16 mm) thick were studied. Values obtained from multiple regression models corresponded well with observed test values. The creep behavior of the panels was explained well by a power-law equation in logarithmic form. Reasonable approximations of total creep deformation at

2-week intervals were made by extrapolating the short-term creep test results.

31. Chow, P. 1983. Veneered fiberboard panels: Effects of moisture and testing speed on hardness properties. Furniture Design and Manufacturing. 55(2): 38–44.

Summary: Maximum face hardness and hardness modulus properties of veneered fiberboard panels were superior to those of plywood and approached those of hard maple and red oak lumber. Moisture condition of veneered fiberboard and other wood-base panels had a significant influence on face hardness properties at both machine testing speeds. However, the two machine testing speeds did not have a significant influence on the face hardness properties. A linear relationship existed between hardness modulus and maximum hardness. Ratio of hardness modulus divided by maximum hardness ranged from 3.8 to 7.7 and decreased with increasing moisture.

32. Cunderlikova, V. 1977. Effect of normal ambient conditions on the properties of wood fiberboard manufactured using the dry process. Drevo. 32(4): 101–102. (Slav. sum.).

Summary: Tests showed that increased moisture content caused a corresponding reduction in board bending strength. In general, for a 1 percent increase in the moisture content, the bending strength decreased by 580 lb/in^2 (4 MPa).

33. Fahey, D.J.; Pierce, D.S. 1973. Role of phenolic resin in imparting properties to dry-formed hardboards. Tappi. 56(3): 53–56.

Summary: Better linear stability and wet strength were achieved with the impregnating resin. For dry strength, the bonding resin was superior. Stiffness was independent of the resin type. Linear stability improved as the amount of the impregnating resin increased, but no change was noted with the bonding resin.

34. Johanson, F.; Back, E.L. 1966. Molding dry ligno-cellulosic materials above 325°C. Forest Products Journal. 16(9): 70.

Summary: Dry board samples were easily bent and molded at temperatures exceeding 617°F (325°C). The softening of the materials was found to be almost entirely reversible on cooling.

35. Myers, G.C. 1978. How adjusting fiber acidity improved strength of dry-formed hardboards. Forest Products Journal. 28(3): 48–50.

Summary: Variations in hardboard modulus of elasticity caused by difference in species mix can be minimized by controlling fiber acidity. Optimum acidity level depends on phenolic resin binder. Linear stability and thickness stability depend more on wood composition than on fiber acidity.

36. Myers, G.C. 1983. Properties of hardboards made from tropical hardwoods and aspen chips before and after simulated outdoor storage. Forest Products Journal. 33(2): 39–42.

Summary: High density hardboards made from aged Philippine chips had greater modulus of elasticity and modulus of rupture values and thickness swelling.

37. Nelson, N.D. 1973. Effects of wood and pulp properties on medium-density dry-formed hardboard. Forest Products Journal. 23(9): 72–79.

Summary: Results indicated that all the strength properties and linear stability were positively correlated with pulp pH. Most strength properties were negatively related to specific gravity of the wood and bulk density of the mat. Linear stability was positively related to the length of wood fiber. Thickness stability was not related to any of the wood or pulp properties analyzed.

38. Pecina, H.; Bernaczyk, Z. 1991. Investigation into the manufacture of hardwood fiberboards in the dry process using lignin-phenol binders. Holz als Roh- und Werkstoff. 49(5): 207–211.

Summary: Hardwood fiberboards can be manufactured in the dry process using lignin-phenol glues with very good mechanical properties and simple technology. Gluing content, pressing regime, and moisture content of the glued fiber materials are important influencing parameters. Resulting boards are characterized by low emissions of harmful substances of volatile formaldehyde and volatile phenol.

39. Smulski, S.J.; Ifju, G. 1987. Flexural behavior of glass fiber-reinforced hardboard. Wood Fiber Science. 19(3): 313–327.

Summary: The flexural stiffness and strength of a dry-process hardboard matrix was significantly improved by internal reinforcement with continuous glass fibers. The modulus of elasticity and modulus of rupture of the board increased with increasing reinforcement volume fraction. Excellent linear correlation among the dynamic modulus of elasticity, the static modulus of elasticity, and the modulus of rupture allowed for estimation of the composite failure stress that was determined nondestructively.

40. Smulski, S.J.; Ifju, G. 1987. Creep behavior of glass fiber-reinforced hardboard. Wood Fiber Science. 19(4): 430–438.

Summary: A significant decrease of the creep deflection of a dry-process hardboard matrix was achieved by internal reinforcement with continuous glass fibers. The total creep deflection and rate of creep deflection of glass fiber-reinforced hardboard decreased with increasing effective reinforcement volume fraction at constant bending stress. Total creep deflection and rate increased with increasing bending stress at constant effective reinforcement volume fractions. The Burger model agreed excellently with observed values.

41. Steinmetz, P.E.; Polley, C.W. 1974. Influence of fiber alignment on stiffness and dimensional stability of high-density dry-formed hardboard. Forest Products Journal. 24(5): 45–50.

Summary: Strength, elastic modulus, and dimensional stability were improved by fiber orientation, with the degree of improvement depending on the percentage of orientation. Tensile strength, tensile modulus of elasticity, and bending modulus of elasticity were improved by orienting alternate layers of fibers perpendicular to the preceding layers. Strength and stiffness were in the range of solid wood values.

42. Suchsland, O.; Woodson, G.E.; McMillin, C.W. 1986. Pressing of three-layer, dry-formed MDF with binderless hardboard faces. Forest Products Journal. 36(1): 33–36.

Summary: The three-layer mat was hot-pressed to overall densities ranging from 44 to 56 lb/ft^3 (704 to 897 kg/m^3). The faces had hardboard-like density, appearance, and characteristics. Face characteristics controlled overall bending strength and bending stiffness. Core characteristics controlled water absorption and linear expansion. This separation of characteristics into face and core allows flexibility in board design.

43. Suchsland, O., Woodson, G.E.; McMillin, C.W. 1987. Effect of cooking conditions on fiber bonding in dry-formed binderless hardboard. Forest Products Journal. 37(11/12): 65–69.

Summary: Increasing steam pressure caused a general improvement in mechanical and physical properties except that linear expansion increased with increasing steam pressure. Bending strength and stiffness peaked at 400 lb/in^2 (2.75 MPa) steam pressure.

44. Suzuki, M.; Iwagiri, S. 1986. Physical properties of hardboard produced by benzylated asplund pulp. Bulletin of the Experimental Forests, Tokyo University of Agriculture and Technology. 22: 25–31. (Jap.; Engl. sum.).

Summary: The authors conclude that 1 to 2 h benzylation is suitable for bonding fibers, increasing elasticity, and resisting swelling.

45. Talbott, J.W. 1974. Electrically aligned particleboard and fiberboard. Proceedings, Particleboard symposium; Pullman, WA: Washington State University. Pullman, WA: WSU: 8: 153–182.

Summary: Electrical alignment has the advantage of being adaptable to a wide range of particle sizes and shapes. Products possess substantially increased directional strength, stiffness, and dimensional stability.

46. Verbesstel, J.B.; Demeulemeester, M. 1977. Applying binder for hardboard in the form of gaseous monomers. Proceedings, Particleboard symposium; Pullman, WA: Washington State University. Pullman, WA: WSU: 11: 63–87.

Summary: To meet the commercial standards, 0.5 to 2 percent of phenol was shown to be active for plasticization. It also increased modulus of elasticity and internal bond strength and decreased water absorption and thickness swelling. Ammonia assisted in developing plasticity and increased the speed of reaction and internal bond. Formaldehyde was shown to increase modulus of elasticity and internal bond and to decrease thickness swelling. A positive correlation between board properties and specific gravity was exhibited.

47. Youngquist, J.A.; Rowell, R.M.; Ross, N.; Krzysik, A.M.; Chow, P. 1990. Effects of steam and acetylated fiber treatment, resin content, and wax on the properties of dry-process hemlock hardboard. Proceedings of 1990 Joint international conference on processing and utilization of low-grade hardwoods and international trade of forest-related products; 1990 June 11–13; National Taiwan University, Taipei, Taiwan: 254–257.

Summary: Heat pretreatment and acetylation improved dimensional stability. Properties measured included modulus of elasticity, modulus of rupture, tensile strength parallel to and perpendicular to board surface, thickness swell, water absorption, and linear expansion. Both 24-h water-soaking and 2-h water-boil tests were conducted to determine the potential use of dry-process hardboards as structural components under high moisture content conditions.

48. Youngquist, J.A.; Muehl, J.; Krzysik, A.; Xin, T. 1990. Mechanical and physical properties of wood/plastic fiber composites made with air-formed dry-process technology. Proceedings of 1990 Joint international conference on processing and

utilization of low-grade hardwoods and international trade of forest related products; 1990 June 11–13. Taipei, Taiwan: 159–162.

Summary: Panels made with yellow cypress fiber had higher strength properties and dimensional stability than did panels made with hemlock fiber. Panels made with the hemlock/polyester/phenolic resin formulation had the highest impact energy values.

49. Yukna, A.D.; Ziedin'sh, I.O. 1970. Use of ammonia during pressing of construction fiberboards. Plastifik. i Modifik. Drevesiny, Riga: 133–135. (Russ. sum.).

Summary: With increasing amount of absorbed ammonia, the density of the boards increased 6.4 percent and static bending strength and tensile strength increased 1.8 times. At a 4.7 to 5 percent content of ammonia, maximum static bending strength and tensile strength were reached.

(Also see references 1, 2, 11, 104, 119, 124, 135, 140, 148, 258, and 260.)

Wet Process (50–83)

50. Back, E.L.; Ostman, B.A.L. 1983. Hardboard stiffness and tensile strength over a moisture and temperature range simulating exterior use. Forest Products Journal. 33(6): 62–68.

Summary: Tensile strength was constant or increased and modulus of elasticity decreased with increasing moisture content up to about 5 percent. Above this level, both properties decreased significantly with a further increase in moisture content. The effect of moisture content on bending stiffness was smaller. Both tensile strength and modulus of elasticity decreased with increasing temperature. The effects on modulus of elasticity are discussed in terms of thermal softening and water as a softener for the amorphous cellulose and hemicellulose polymer.

51. Back, E.L.; Salmen, L.; Richardson, G. 1983. Transient effects of moisture sorption on the strength properties of paper and wood-based materials. Svensk Papperstiding. 86(6): R61–R67.

Summary: During desorption and absorption of moisture, lignocellulosic materials show transient effects on mechanical properties. These effects mainly consist of a temporary reduction in stiffness, e.g., modulus of elasticity, and an increase in creep rate. Transient effects during absorption and desorption are described, followed by some experimental examples. Critical experiments with a constant moisture gradient through the material are presented as well. Some practical consequences for packaging paper and other wood-based materials are given together with a means for reducing the effects of moisture.

52. Biblis, E.J. 1991. Engineering properties of commercial hardboard lap siding. Part 2. Smooth boards. Forest Products Journal. 41(3): 45–49.

Summary: Test results indicate significant differences in the majority of properties of hardboards from five different manufacturers. Although the tested properties meet the established commercial standards for hardboard siding boards, certain board properties from some manufacturers are twice as strong as that of boards from other manufacturers. The level of retention of several properties of these boards after soaking and cycling is higher than the retention level of any other structural wood panels.

53. Carll, C.; Eslyn, W.; Myers, G.C.; Brewer, W.; Staton, D. 1985. Evaluation of black locust (*R. pseudoacacia*) as raw material for wet-process hardboard. Forest Products Journal. 35(3): 11–17.

Summary: Fiber from small whole locust stems can be made into wet-process hardboards with good modulus of elasticity in bending property. Storage for 2 years in a climate of 80°F (26°C) and 90 percent relative humidity did not result in any consistent loss of properties in hardboards made from whole-stem locust. However, the boards showed poor exterior durability.

54. Chow, P.; McNatt, J.D.; Youngquist, J.A. 1985. The proportional limits of lateral nail resistance in structural wood composites. Proceedings, Timber engineering conference (3), Forest Products Research International Achievement and the Future. S. Africa. 2–4: 9 p. Vol. 4.

Summary: Performance on the load-deformation level at the elastic limit or elastic behavior in compression of the lateral fastener resistance was determined in hardboard siding and four other wood composites. Testing involved three exposure conditions, three test methods, and two face-grain directions.

55. Gavrilidin, E.A.; Laskeev, P.K.; Perepelkin, K.E. 1976. Thermohydroplastic fibers from polyvinyl alcohol in the production of hardboards. Sb. Tr. VNII Tsellyul.–Bumazh. Prom. (Issled. Oblasti Khim. Tekhnol. Proizvod. 8 Bumagi Kartona). 69: 71–74. (Russ. sum.).

Summary: Hardboard containing thermoplastic polyvinyl alcohol fibers had increased strength and water resistance. Hardboard with bending strength

of 8.7 x 10^3 lb/in^2 (60 MPa) and a 24-h water absorption of 20 percent could be produced from pinewood fibers containing 4 to 4.5 percent thermoplastic polyvinyl alcohol fibers. Stronger binder action was also obtained with polyvinyl alcohol fibers.

56. Gertjejansen, R. 1969. Wet process hardboards from aspen sapwood and discolored heartwood. Forest Products Journal. 19(9): 103–107.

Summary: Wet process hardboards made from discolored aspen (*Populus tremuloide*) heartwood had lower modulus of elasticity, modulus of rupture, and internal bond strength than did hardboards made from aspen sapwood.

57. Hsu, S.T. 1977. Interrelationships of density and fiber orientation on the mechanical properties of fiberboard. University of Washington. Ph.D. thesis. 97 p.

Summary: The modulus of elasticity of fiberboard was exponentially related to density with an exponent of approximately 2 for all levels of fiber orientation. The modulus of rupture was also related to density but with an exponent range from 2.20 to 2.54. A new orientation index was developed and a mathematical formula was derived to express the relationship between the new index and average fiber angle.

58. Ivanov, S. 1981. A method for production of multilayer water resistant wood fiberboard. Dervoobrabot–vashchai Mebelna Promishlenost. 24(5): 140–142.

Summary: Five-layered waterproofed fiberboards exhibited approximately equal bending strength to seven-layered water-resistant plywood; this was double the strength of three-layered fiberboards. An increase in moisture content of the boards reduced strength. It is suggested that board edges and holes should be protected from moisture.

59. Johanson, F.; Back, E.L. 1966. Thermal softening of dry ligno-cellulosic materials. Svensk Papperstiding. 69: 199.

Summary: Dry ligno-cellulosic materials softened approximately reversibly between 608°F (320°C) and 806°F (430°C), if heated rapidly enough to minimize degradation and cross-linking. The material that can be bent or molded at these temperatures will then regain stiffness and most strength properties upon cooling. If increased strength properties and dimensional stability are desired, the molded board may then be heat-treated in air in the usual manner.

60. Kalina, M. 1972. Rheological behavior and long-term strength of plywood, particle board, and hard fiberboards. Holztechnologie. 13(3): 172–175. (Ger.; Engl. sum.).

Summary: This paper reported the results of measurements of deflection in bending over periods up to 50 days. The rheological characteristics of the materials were compared, and the data were extrapolated up to 1 year.

61. Kelly, M. 1972. Failure characteristics of polyurethane-foam-cored struts faced with hardboard. Composites (University of Bath, England). 3(4): 175–177.

Summary: A number of low density polyurethane-foam-cored struts faced with hardboard were tested under comprehensive axial loads. Direct comparison of experimental results and theory was made using a form of Southwell plot. Inelastic behavior prior to failure was observed.

62. Kitahara, K.; Perng, W.T. 1965. On the creep of hardboard (and solid wood beams of *Chamaecyparis obtusa*). Journal of Japan Wood Research Society. 11(3): 88–92. (Jap.; Engl. sum.).

Summary: Creep deflection of hardboard was large and showed no trend of leveling off. Mathematical formulas for deflection as a function of time and stress were developed. The rate of creep was found to be much greater in hardboard than in solid wood. The stress of the creep limit was very low, about 1 percent of the rupture stress of hardboard at equal rates of creep strain.

63. Kitahara, K.; Perng, W.T. 1969. On the viscoelastic properties of hardboard. Journal of Japan Wood Research Society. 15(4): 154–159. (Jap.; Engl. sum.).

Summary: The viscoelasticity of hardboard conforms to the superposition principle. A model of this behavior is sketched. Curves of retardation spectra as a function of retardation time show maximum on a log–log scale and seem to differ from similar curves for wood and particleboard.

64. Kums, U. 1978. The flexibility of hardboards. LLA (Latvijas Lauksaimniecibas Akademija) Raksti. 163: 35–42.

Summary: Experiments were made on the possibility of hot-bending hardboards to make parts for furniture. The best results were obtained with boards of 0 to 3 percent moisture content, temperatures of 572°F to 608°F (300°C to 320°C), and heating for 20 to 50 s.

65. Kums, U. 1981. Effect of contact heating on the physical and mechanical properties of fiberboards. Raksti, Latvijas Lauksaimnecibas akademija. 185: 58–64. (Latvian; Russ. sum.).

Summary: Changes in modulus of elasticity and deflection to point of rupture were measured for fiberboards made at different temperatures and durations of contact heating, and with or without prior treatment with gaseous NH_3. Deflection of up to 11 mm was possible without rupture at 212°F (100°C) in boards treated with NH_3 compared to 570°F (300°C) for untreated boards. The optimal modulus of elasticity was achieved with contact heating of treated boards for 40 s.

66. Law, K.N. 1974. Study of fiber orientation in hardboard. University of Toronto. Ph.D. thesis. (Available from University Microfilms, Ann Arbor, MI.)

Summary: In comparison to the random boards, modulus of elasticity, dimensional stability, tensile strength, and modulus of rupture of multi-ply oriented boards were increased in the direction of orientation and decreased in the direction normal to that of orientation.

67. Law, K.N.; Balatinecz, J.J. 1975. Some properties of oriented hardboard. Svensk Papperstiding. 78(4):130–134. (Engl.; Swed.; Ger. sum.).

Summary: In unidirectional panels, tensile strength increased 54 percent, rupture modulus 59 percent, elastic modulus over 86 percent, and dimensional stability about 57 percent over comparable random panels. Hence, hardboards with high fiber orientation can be important where extra stability and strength are desired.

68. Liptsev, N.V.; Chibirev, V.E. 1981. Temperature–time equivalence of hydrothermal treatment of pinewood during fiberboard production. Mezhvuz. Sb. Nauch. Tr., Khim, Mekh. Pererab. Drev. i Drev. Otkhodov (Kiprianov, A. I., ed.). 7: 87–92. (Russ. sum.).

Summary: Hydrothermal treatment of chips with saturated steam was used to soften wood before refining. The duration of steaming at different temperatures necessary to maintain required chip properties (determined by modulus of elasticity) was studied. Based on calculated data, a nomogram was constructed for determining the duration and temperature of pinewood steaming at a fixed change in elastic properties.

69. Martensson, A. 1988. Tensile behavior of hardboard under combined mechanical and moisture loading. Wood Science and Technology. 22(2): 129–142.

Summary: The effect of moisture variations on tensile creep of hardboard was much smaller in comparison to that of other wooden materials. With constant stress, strain increased after the first sorption, with the main increase exhibited during the first relative humidity cycle. At constant strain, the effect of mechanical loading on creep was greater. A simple mathematical model was developed to simulate the experiments.

70. Martincek, G.; Benicak, J. 1972. Determination of wood hardboard elasticity by the phase velocity method. Drevarsky vyskum. 17(3): 155–164. (Slovak.; Russ.; Ger.; Engl. sum.).

Summary: Using boards conditioned at temperatures of 68°F (20°C) (±2°) and 65 percent relative humidity, the propagation velocity of the bending, longitudinal, shearing, and Rayleigh stressed within the 3,000 to 35,000 Hz frequency range was measured. Based on the phase velocities obtained, the Poisson coefficients and the elastic moduli of the tested boards were calculated.

71. Naidu, M.V.; Victor, V.J. 1976. Modulus of rigidity of wood-based panels. Part II: Hardboard and particle board. IPIRI Journal. 6(2): 90–94. Indian Plywood Industry Research Institute, Bangalore, Karnataka, India.

Summary: The rigidity modulus of oil-tempered hardboard was approximately 3.5 times that of plywood of the same thickness, and approximately 1.5 times that of particleboard of double the thickness. The size of the hardboard specimens considerably affected the rigidity modulus value obtained, and the rigidity modulus determined by loading on the screen side was approximately 2.5 percent greater than that determined by loading on the smooth side. The rigidity modulus/modulus of elasticity ratios of the hardboard and particleboard indicated that these materials are suitable for structural uses.

72. Nam, Z.; Hayashi, S.; Ishihara, S. 1979. Properties of fiberboard made from asplund pulp-poly methyl methacrylate composite. Zairyo/Journal of the Society of Materials Science, Japan. 28(310): 647–652. (Jap. sum.).

Summary: Graft copolymerization of methyl methacrylate onto wood fibers was investigated, and the effects of the grafting on dimensional stability and strength properties of the fiberboard were examined. Modulus of rupture and modulus of elasticity of the fiberboard in bending increased with increasing degree of grafting, but the effect of grafting was

less than that caused by urea- or phenol-formaldehyde resin.

73. Narayanamurti, D.; Aswathanarayana, B.S. 1969. Note on creep in hardboard. Indian Pulp Paper. 24(3): 181–182.

Summary: Standard hardboard was more prone to creep than oil-tempered hardboard.

74. Norberg, K.G.; Back, E.L. 1968. Effects of hot pressing temperature on the properties of hard-board and semi-hard fiber building boards. Svensk Papperstidning. 71: 774–787.

Summary: At press temperatures of 167°F to 257°F (75°C to 125°C), dry but not wet X–Y strength and modulus of elasticity increased with increasing press temperature, which was interpreted as an increase in hydrogen bonding. Part of this strength increase may also depend on built-in stresses, which increased with increasing press drying to a higher dryness. Water absorption and thickness swelling at a given sheet density after 24-h water immersion both increased with increasing press temperature up to a slight maximum at about 257°F (125°C) above which they decrease. In the range 257°F (125°C) to about 320°F (160°C), press temperature had no significant effect on strength properties. Impact strength perpendicular to sheet decreased rapidly above 392°F to 437°F (200°C to 225°C).

75. Norberg, K.G.; Back, E.L. 1969. Effect of refining on strength properties of press dried hard and semi-hard fiber building boards. Svensk Papperstidning. 72: 649–655.

Summary: The main effect of refining on both press-dried and air-dried building board sheet properties occurred in the pulp freeness range of 15 to 30 s with a simultaneous improvement of Z–strength, dry and wet X–Y strength, specific breaking energy, and both modulus of elasticity and specific impact strength.

76. Ogland, M.J.; Emilsson, E. 1951. The effect of heat treatment on the bending strength and elasticity of hardboards. Svensk Papperstiding. 54(17): 597–600.

Summary: Heat treatment of hardboard increased stiffness, bending strength, modulus of elasticity, and elastic bending strength.

77. Ota, M.; Tsutsumi, J.; Koga, T. 1961. Studies on the manufacturing conditions of hardboard from Himeshira (*Stewartia monadelpha*). Part I. The effect of defibrate conditions on the properties of hardboard. Reports of the Kyushu University Forest Experiment Station. 15: 187–199. (Jap. sum.).

Summary: Moisture content and hardboard bending strength decreased with increasing preheating time (4, 6, 8, and 10 min), but specific gravity increased. Yield of pulp decreased, but modulus of elasticity, modulus of rupture, and hardness increased with increasing defibrating time (0.5, 1.0, 1.5, and 2.0 min) under constant steam conditions 347°F (175°C).

78. Ota, M.; Kawabe, J.; Yamaguchi, H. 1974. Studies on the strength properties of S1S hard-board. Part 3. On the effect of sizing. Reports of the Kyushu University Forest Experiment Station. 25: 161–166. (Jap.; Engl. sum.).

Summary: The effects of sizing on the waterproof properties and mechanical strength of wet-process hardboard were investigated. The modulus of rupture was markedly increased by the addition of up to 1 to 2 percent phenol-formaldehyde resin as a sizing agent. The stress at proportional limit in bending was also increased by use of phenol-formaldehyde resin, but Young's modulus in bend-ing was not affected.

79. Ota, M.; Kawabe, J. 1976. Studies on the strength properties of S1S hardboard. Part 4. Manufacture of fiberboard core plywood. Reports of the Kyushu University Forest Experiment Station. 26: 141–147. (Jap.; Engl. sum.).

Summary: The optimum gluing condition for the manufacture of plywood with a hardboard core and surface veneers of red lauan are described. Test results showed that the values of Young's modulus obtained for hardboard-core plywood and veneer-core plywood were almost equal for plywood of similar thickness, but the value of specific Young's modulus for hardboard-core plywood was only half that of veneer-core plywood.

80. Palms, J.; Sherwood, G.E. 1979. Structural sandwich performance after 31 years of service. Res. Pap. 342. U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 17 p.

Summary: In experiments conducted between 1947 and 1978, 0.125-in. (3-mm) and 0.25-in. (6-mm) hardboard, 0.125-in. (3-mm) tempered hardboard, and 0.125-in. (3-mm) aluminum overlaid hardboard were used as facing in construction of corrugated core sandwich panels intended for house construc-tion. In stiffness, plywood-faced panels performed best. Panels faced with hardboard, aluminum, and paperboard tended to decrease in strength. Bowing of wall and roof panels was observed over a 15-year period for original panels and 4-year period for panels installed in 1962. North-oriented panels using hardboard facing were flat in the summer and bowed out to a maximum 0.5 in. (12.7 mm) in the

spring. South-oriented panels bowed out continuously throughout the year between 0.25 in. (6 mm) and 0.4 in. (10 mm).

81. Perkitny, T.; Perkitny, J. 1966. Comparative investigations concerning deformation in wood, particleboard, and fiberboard resulting from a long-term constant bending load. Holztechnologie. 7(4): 265–270. (Ger.; Russ.; Engl. sum.).

Summary: Under bending loads of 20 and 40 percent of breaking load and at moisture contents of 0 to 20 percent, wood, particleboard, and fiberboard exhibited the relative creep coefficient values of 1, 4, and 5, respectively.

82. Schwartz, S.L.; Baird, P.K. 1950. Effect of molding temperature on the strength and dimensional stability of hardboards from fiberized water-soaked Douglas-fir chips. Proceedings, Forest Products Research Society 4: 322–326.

Summary: Douglas-fir hardboard prepared from pulps produced by fiberizing water-soaked chips were dried and heat-treated in one short operation in a hot press at temperatures in excess of 392°F (200°C). This resulted in a molding time of less than 10 min and an increase in flexural strength and in dimensional stability in thickness. However, a reduction in toughness was also observed. Raising the maximum temperature for a 5-min molding period increased the flexural strength 32 percent, stiffness 19 percent, and water resistance 33 percent. It also decreased swelling and recovery 27 percent upon humidification.

83. Watkinson, P.J.; Van–Gosliqa, N.L. 1990. Effect on physical and mechanical properties of New Zealand wood composites. Forest Products Journal. 40(7/8): 15–20.

Summary: The effects of a range of moisture content values induced by different relative humidities were studied for tempered hardboard, urea-formaldehyde bonded flooring particleboard, and medium density fiberboard commercially available in New Zealand. The moisture contents, dimensional changes, and mechanical properties were recorded after the moisture contents were close to equilibrium. There were significant differences between the control humidity and the other humidities pooled for modulus of elasticity, modulus of rupture, internal bond strength, and compressibility. However, for tempered hardboard, controls were only different from the other humidities for modulus of elasticity and compressibility. The effects of moisture content on physical dimensions, modulus of rupture, and modulus of elasticity were similar to those reported by other researchers for particleboard and hardboard.

(Also see references 104, 196, 264, and 265.)

Dry and Wet Processes (84–119)

84. Boehme, P. 1967. Deformation problems with asymmetrically surface-finished hardboard. Holztechnologie. 8(1): 11–16. (Ger.; Russ.; Engl. sum.).

Summary: Results indicated that the requirements of hardboard pressed with a surface layer of melamine-resin-impregnated paper must include a modulus of elasticity $\geq 40 \times 10^3$ kp/cm^2 and a thickness $\geq 0.16 \pm 0.01$ in. ($\geq 0.4 \pm 0.03$ cm) to avoid excessive deformation.

85. Chan, W.W.L. 1979. Strength properties and structural use of tempered hardboard. Journal of the Institute of Wood Science. 8(4): 147–160.

Summary: This report is an explanation for the inclusion of tempered hardboard in an Amendment to British Standard Code of Practice CP112: The structural use of timber. The derivation of permissible design stresses and modification of modulus of elasticity by creep are discussed.

86. Chow, P.; Noack, D.; Deppe, H.J. 1978. Utilization and specifications of wood and wood-base materials in West Germany. Forest Products Journal. 28(12): 17–20.

Summary: This paper reports the progress of wood and wood-base materials utilization, marketing, specification, research, and development in West Germany. Statistics about such factors as production and sales are presented. Also, some specifications for wood and wood-base products are introduced, including the minimum requirements of modulus of elasticity for hardboard.

87. Elias, E.; Baker, W.A. 1986. Structural performance of wood-based siding. Res. Rep. 148. Tacoma, WA: American Plywood Association.

Summary: Structural performance of various wood-based siding products, including hardboard, plywood, particleboard, wood, aluminum, vinyl, and wood composites, was evaluated under uniform load, concentrated static load, and other tests. Overall results indicated that most wood-based siding currently used will meet existing building code requirements.

88. Fraipont, L. 1976. Evolution of some characteristics of hardboards during three year's exposure to weathering. Rapport Activite 1975, Station Technol. Forest., Gembloux, Belgium: 121–219. (Fr.; Engl. sum.).

Summary: Strength-loss ranges for modulus of rupture were 15 to 58 percent after 1 year and 20

to 65 percent after 3 years. For modulus of elasticity, strength loss ranged from 4 to 64 percent after 1 year and to 22 to 75 percent after 3 years.

89. Haygreen, J.; Sauer, D.J. 1969. Prediction of flexural creep and stress rupture in hardboard by use of a time–temperature relationship. Wood Science. 1(4): 241–249.

Summary: The effect of temperature on the mechanical properties of two types of hardboard was studied. The modulus of rupture of the wet-process board was affected to a greater extent by temperature than was the dry-process board. However, the deflection at failure of the wet-process board was less sensitive to temperature than that of the dry-process board. Both modulus of rupture and deflection at failure appear to be linear functions of temperature in the range 0°F to 200°F (93°C).

90. Hrdlicka, I.; Matysek, V. 1978. Use of wood fiberboard in the manufacture of furniture. Drevo 33(4): 118–120 (April 1978). (Czech. sum.).

Summary: Board thickness ranged from 0.13 to 0.20 in. (3.3 to 5 mm). Special attention is paid to the use of these materials for drawer bottoms. Bending strength data are shown for the studied materials.

91. Hilson, B.O.; Rodd, P.D. 1985. The structural use of tempered hardboard—some recent research. Journal of the Institute of Wood Science. 10(3): 108–110.

Summary: The results were used to estimate the factors of safety that are implicit in the design procedures adopted for hardboard-webbed beams in BS5268:1984. These factors were found to be much larger than those normally adopted for timber structures.

92. Hofstrand, A.D. 1958. Relationship of specific gravity to moduli of rupture and elasticity of commercial hardboard. Forest Products Journal. 8(6): 177–180.

Summary: Thirty-six types of commercial hardboard were tested in static bending. Significant correlations existed for almost every type of hardboard between specific gravity and modulus of rupture and between specific gravity and modulus of elasticity. However, no one single equation gave accurate corrections for moduli of elasticity or rupture when compensating for differences in specific gravity.

93. Krisnabamrung, W.; Takamura, N. 1968. Suitabilities of some Thai hardwood and coconut fiber for manufacturing hardboards by wet and dry processes. Journal of Japanese Tappi. 22(3): 154–164. (Engl.; Jap. sum.).

Summary: *Sterculia* and rubberwood (*Hevea*) boards showed fair mechanical strength but required further treatment for water repellency. Boards from coco fiber showed outstanding flexibility compared with wet-process hardwood boards. Teakwood was best for wet-process hardboard, but may yield satisfactory dry-process board.

94. Mataka, Y. 1985. Response of warp and internal stress in fiberboard to change of environmental conditions. Zairyo/Journal of the Society of Materials Science. 34(383): 942–948.

S1S (wet-process) hardboard was conditioned at 68°F (20°C) and 60 percent relative humidity. At 104°F (40°C) and 90 percent relative humidity, moisture absorption caused warp of both face and back of boards. Similarly, warp resulted from moisture desorption at 104°F (40°C) and 30 percent relative humidity.

95. McCallum, J.M.; Brown, D.S. 1982. SAE classification system for fiberboard. SAE Tech. Pap. Series (Int. Cong. Detroit) 820–200: 4 p. (Available from Society of Automotive Engineers, 400 Commonwealth Dr., Warrendale, PA 15096.)

Summary: A numbering-lettering system for specifying pertinent properties of automotive fiberboards has been developed by the SAE Fiberboard Subcommittee. The alpha–numeric code characters denote basic characteristics and performance levels of supplementary properties, notably weight, moisture content, water absorption, bending modulus, and stiffness.

96. McNatt, J.D. 1970. Design stress for hardboard: effect of rate, duration, and repeated loading. Forest Products Journal. 20(1): 53–60.

Summary: The effects of rate of loading and duration of load on the strength of hardboard were evaluated. The fatigue strength in tension and shear for 10 million cycles of stress was also determined. The behavior of hardboard under different loading conditions was found to be similar to that of solid wood.

97. McNatt, J.D. 1974. Effects of equilibrium moisture content changes on hardboard properties. Forest Products Journal. 24(2): 29–35.

Summary: The equilibrium moisture content of 0.25-in. (6.35-mm) tempered hardboard varied from 4 percent at 30 percent relative humidity to 10.9 percent at 90 percent relative humidity. Values for strength and elastic properties, expressed as percentages of the value at 65 percent relative humidity, ranged from 100 to120 percent between ovendry and 50 percent relative humidity and from

70 to 90 percent at 90 percent relative humidity. Changes in relative humidity affected interlaminar shear modulus more than any other property.

98. McNatt, J.D. 1980. Hardboard-webbed beams: Research and application. Forest Products Journal. 30(10): 57–64.

Summary: Several long-term load studies, principally on I-sections, indicate that hardboard-webbed beams perform in a manner similar to the performance of plywood-webbed beams. A number of countries, including England, Germany, and Sweden, have published allowable design loads for structural use of hardboard. Results of this research are described. Figures illustrate built-up beam construction techniques and actual beams being tested and in use.

99. McNatt, J.D.; Superfesky, M.J. 1983. Long-term load performance of hardboard I-beams. Res. Pap. FPL–441. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 10 p.

Summary: Built-up I-beams with hardboard shear webs and laminated veneer lumber flanges exhibited satisfactory performance when subjected to constant loads for 5 years in interior, protected exterior, and controlled cyclic humidity environment. Creep deflection was greatest for controlled cyclic humidity and least for interior. For beams loaded at the same stress level in a given environment, deflection was greater in beams made with web material having a lower shear stiffness.

100. Morze, Z.; Synowiec, J. 1979. Changes in the elasticity of high density hardboard under the effect of moistening and drying cycles. Holzforschung und Holzverwertung. 31(1): 9–14. (Ger.; Engl. sum.).

Summary: Hardboards were subjected to heat treatment with drying oil or phenol formaldehyde resin. After six moistening and drying cycles between 95 percent and 36 percent relative humidity at 68°F and 104°F (20°C and 60°C), irreversible breakdown of secondary bonds occurred, with decrease in elastic moduli.

101. Moslemi, A.A. 1964. Some aspects of viscoelastic behavior of hardboard. Forest Products Journal. 14(8): 337–342.

Summary: Two types of hardboard differing only in the process of manufacturing were subjected to creep testing at various load levels. The effect of moisture content on the behavior of the two hardboards was studied in terms of the elements of an analog model. Some results were compared with those obtained through static testing.

102. Moslemi, A.A. 1964. Effects of moisture content, the process of manufacture and load on the creep and relaxation of hardboard. Quarterly Bulletin of the Michigan Agricultural Experimental Station. 47(2): 271–291.

Summary: Two types of hardboard, different in manufacturing techniques, were subjected to creep in bending. These creep tests were carried out at three levels of moisture content and three levels of loading, ranging from approximately 10 to 60 percent of the ultimate bending strength. The test results indicate that among the three moisture content (MC) levels, the intermediate MC of 6 to 8 percent produced the lowest creep deflections while the high MC of 16 to 19 percent incurred the highest creep deflections. The technique of manufacture did not influence the creep results at low and intermediate MC to a significant extent. Higher stresses resulted in higher magnitudes of creep deflections in all boards at all levels of moisture content.

103. Moslemi, A.A. 1967. Dynamic viscoelasticity in hardboard. Forest Products Journal. 17(1): 25–33.

Summary: The article attempts to explain the behavior of hardboard as a function of its moisture content. The objectives were to determine the extent that the viscoelastic behavior of hardboard can be revealed through nondestructive testing and to determine the influence of moisture content on the viscoelastic behavior of hardboard as revealed by nondestructive testing methods. Possible application of the nondestructive testing method for industry research and quality control purposes is discussed.

104. Myers, G.C.; McNatt, J.D. 1985. Fiberboard and hardboard research at the Forest Products Laboratory: A 50-year summary. Gen. Tech. Rep. FPL–47. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 39 p.

Summary: Nearly 150 research papers are reviewed in this summary of achievements in the field of fiberboard and hardboard by researchers at the Forest Products Laboratory during a 50-year period. The reports describe various mechanical properties and dimensional stability of hardboard as well as methods for improving water resistance, thickness swelling, and related properties.

105. Myers, G.C.; Crist, J.B. 1986. Feasibility of manufacturing hardboard from short-rotation intensively cultured *Populus*. Forest Products Journal. 36(1): 37–43.

Summary: A hybrid poplar, *Populus* Tristis No. 1, grown under short-rotation intensive culture, was investigated as a possible raw material for the manufacture of hardboard. Hardboards were evaluated for modulus of elasticity and dimensional change, and test results were analyzed statistically. Results indicate that intensively cultured *Populus* raw material is suitable for manufacturing hardboards.

106. Myers, G.C. 1986. A comparison of hardboards manufactured by semidry, dry, and wet-formed processes. Forest Products Journal. 36(7/8): 49–56.

Summary: Measurements of modulus of rupture, modulus of elasticity, and tensile strength parallel and perpendicular to the surface showed that the strength properties of semi-dry formed hardboards were lower than those of wet-formed hardboards but higher than those of dry-formed hardboards. Semi-dry formed hardboards were more stable (linear and thickness change) than hardboards formed by the other processes and required more phenolic resin than wet-formed but less than dry-formed hardboards.

107. Noack, D.; Roth, W.; Wiemann, D. 1984. Bending tests with thin wood based boards. Holz als Roh- und Werkstoff. 42(9): 343–344.

Summary: Problems are discussed relating use of Deutsches Institut für Normung (DIN) standard methods (52352, 52362, 52371) for determining bending strength in thin (<0.4 in. (<10 mm)) panels. Recommendations are presented for alterations to the methods, based on studies on 0.112- to 0.157-in. (3- to 4-mm) hardboard, 0.157-in. (4-mm) particleboard, and 0.112-in. (3-mm) three-ply beech plywood.

108. Oertel, J. 1968. Comparative investigation on particleboard and hardboard. Holztechnologie. 9(3): 153–158.

Summary: Maximum elastic deformation of fiberboard specimens under compression and bending load occurred in a moisture content range of 4 to 6 percent.

109. Oertel, J. 1968. Comparative studies on wood particle boards and hardboards.1. Relationships between dynamic modulus of elasticity, static modulus of elasticity, density, and bending strength. Holztechnologie. 9(1): 24–29. (Ger.; Russ.; Engl. sum.).

Summary: Bending strength and modulus of elasticity of hardboards reached a maximum as board moisture content was increased between 1 and 3 percent. The difference between static and dynamic moduli of elasticity increased with increasing board moisture content. Correlation of coefficients showed that the relationship between dynamic modulus of elasticity and bending strength is basically independent of moisture content and materials.

110. Ozarska–Bergandy, B.; Ganowicz, R. 1985. Postbuckling behaviour of hardboard under shear. Wood Science and Technology. 19(4): 353–361.

Summary: Two series of 15.8- by 15.8- by 0.13-in. (400- by 400- by 3.2- mm) and 15.8- by 15.8- by 0.16-in. (400- by 400- by 4.0-mm) hardboard were tested experimentally in a special apparatus that was supposed to satisfy the boundary and load conditions. During increasing shear load, hardboard deformations were measured to determine the first and second critical loads and failure load. The experimental results were compared with a numerical solution based on the von Karman nonlinear theory of plates. A good agreement of experimental results with the theoretical solution was achieved.

111. Ramaker, T.J.; Davister, M.D. 1972. Predicting performance of hardboard in I-beams. Res. Pap. FPL 185. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 12 p.

Summary: Close agreement between the theoretically predicted values of deflection and strength, and the results of tests confirmed that the performance of hardboard in a structure can be predicted.

112. Sauer, D.J.; Haygreen, J.G. 1968. Effects of sorption on the flexural creep behavior of hardboard. Forest Products Journal. 18(10): 57–63.

Summary: The flexural creep behavior of wet- and dry-process hardboards was greatly influenced by sorption. Adsorption produced far greater creep than that derived during constant or desorption conditions. Increases in temperature and stress level during constant or changing sorption conditions produced an increase in creep. Dry-process hardboard exhibited greater creep than wet-process hardboard except under low stress and moisture conditions.

113. Stillinger, J.R.; Coggan, W.G. 1956. Relationship of moisture content and flexural properties in 25 commercial hardboards. Forest Products Journal. 6(5): 179–186.

Summary: Hardboards were tested for moisture content, modulus of rupture, modulus of elasticity, work to maximum load, and work to a 0.2-in. (5.08-mm) deflection. As the moisture content of the

boards decreased, modulus of rupture, modulus of elasticity, and work to 0.2-in. (5.08-mm) deflection increased while work to maximum load decreased. Modulus of rupture was reached between 30 percent relative humidity and oven-drying conditions. Modulus of elasticity showed a similar pattern. The increase in bending strength and stiffness of the boards conditioned at low relative humidities was accompanied by a loss in work to maximum load because of the embrittlement of the boards attended by loss of moisture.

114. Sutula, P.R.; Moslemi, A.A. 1973. Effects of three cyclic constant levels of moisture content on creep deflection in hardboard. Forest Products Journal. 23(3): 50–55.

Summary: Flexural creep tests were made on wet- and dry-process hardboards over three cycles of humidification (up to 18 percent moisture content) and drying. All three components of creep were initially much greater in the dry-process boards, especially in the second cycle, but decreased in the third cycle so that their behavior was similar to that of the wet-process boards.

115. Suchsland, O.; Woodson, G.E.; McMillin, C.W. 1985. Binderless fiberboard from two different types of fiber furnishes. Forest Products Journal. 35(2): 63–68.

Summary: Fiber furnishes from two commercial processes were used to make experimental hardboards by four possible methods: wet formed (pressed dry and wet) and dry formed (pressed dry and wet). Since no adhesives were added, all bonding was due to natural agents. Results of mechanical and physical testing of the hardboards indicated that high quality hardboard can be made from binderless, ovendry furnish and that the pulping conditions are more critical with regard to board quality than are pressing conditions (wet or dry).

116. Superfesky, M.J.; Ramaker, T.J. 1976. Hardboard-webbed I-beams subjected to short-term loading. Res. Pap. FPL 264. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 12 p.

Summary: The results indicate that the behavior of hardboard-webbed I-beams subjected to short-term loading can be predicted reasonably well using fundamental engineering theory together with the properties determined from small specimen evaluation.

117. Superfesky, M.J.; Ramaker, T.J. 1978. Hardboard-webbed I-beams: Effects of long-term loading and loading environment. Res. Pap. FPL–306. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 18 p.

Summary: Twelve-in. (30.48-cm) and 6-in. (15.24-cm) I-beams with webs of wet- and dry-formed hardboard and plywood were subjected to constant loads in three different humidity environments. After 17,000 h, the performance of the hardboard-webbed I-beams appeared to be at least comparable to that of I-beams with plywood webs.

118. Walter, W.J. 1983. Manufacturing automotive interior panels from fiberboard. SAE Tech. Pap. Series. Publications by Society of Automotive Engineers, Warrendale, Pennsylvania.

(This abstract is not available.)

119. Windaus, G.; Petermann, E.; Steinig, J.; Johansen, B. 1975. Electrical measurement of physical values in paper testing (8). Comparison of quasistatic and dynamic bending stiffness of solid-fiber boards of different dry contents and contribution to the buckling of slender samples and rectangular corners. Verpackungs–Rundschau. 26(4): 27–34. (Ger.; Engl. sum.).

Summary: The bending stiffness of solid-fiber board as measured by the quasistatic method was found to show good correlation with values found via the dynamic resonance method. The buckling test can also be applied to determining bending stiffness as long as the samples are sufficiently slender. Compression tests on right-angle corner pieces of solid-fiber board revealed that corner stabilization has a decisive influence on compression strength.

(Also see references 22, 23, 26, 28, and 227.)

Patents

Dry Process (120–122)

120. Grayson, M.H. 1985. Warp resistant lightweight high strength board has expanded polystyrene core sheet bonded between fibre-board facing sheets. Assignee: (SALE) SALESCO PTY LTD Assignee codes: Document type: A.N.: AU 8334219 A.D.: 831012 P.N.: AU 8434219 I.D.: 850418.

Summary: Board has a core sheet of expanded polystyrene between and bonded to fiberboard facing sheets. The core sheet is about 0.16 to 23.6 in. (400 to 600 mm) thick and has a density of 1.56 to 1.87 lb/ /ft^3 (25 to 30 kg/m^3), while the facing sheets have a thickness of 0.079 to 1.38 in. (2 to 35 mm) and density of 37 to 50 lb/ft^3 (600 to 800 kg/m^3). This board is suitable for load-bearing and partitioning walls, furniture and roofing panels, and internal and external doors. It is lightweight and has high dimensional stability.

121. Grignon, J. 1985. Hardboard-like panel and its production. Assignee: Domtar Inc. Assignee codes: Document type: Patent, A.N.: Can. appln. 418,296 A.D.: Dec. 22, 1982. P.N.: Can. pat. 1,193,181. I.D.: Sept. 10, 1985.

Summary: A rigid lightweight panel for use as siding consists of a rigid core and a wrapping of resin-impregnated paper surrounding the core, which consists of a mixture of wood fibers and asphalt. The asphalt is 10 to 30 percent by weight of the core, and at least 50 percent by weight of the volume of the core is air cells. The wrapping is glued to the core with a suitable adhesive, such as a weatherproof polyester glue.

122. Kuzmich, N.S.; Kutsak, A.A.; Sinitski, V.I. 1983. Fiberboard surfacing involves dampening one surface over its entire area and the other partially, in strips, to prevent buckling. Assignee: Beloruss. Kirov. Techn. Ins., Document type: Patent, P.N.: SU 992240, I.D.: 830205.

Summary: Exterior and interior surfaces are hot-pressed onto prepared surfaces of boards and left to set. To prevent buckling, one surface is dampened 2 to 8 percent more than the other before being pressed on. One surface is dampened over its entire area and the other partially, in strips. This prevents buckling and enables cheaper surfacing materials, e.g., paper-based ones, to be used for surfaces not seen during use, and natural wood veneer or decorative laminates for external surfaces. Buckling does not exceed 25.4 in./0.3 ft (1mm/m) after 24 h.

Wet Process (123–124)

123. Back, E.L. 1977. Method of making wet-pressed fiberboard of high resistance to bending. Document type: Patent, P.N.: US 4,032,394.

Summary: During the manufacturing process, the pressed board product contains strip-like surface portions of varying densities that extend in at least one direction of the horizontal plane of the sheet, whereby the finished board has a higher resistance to bending than a homogeneous sheet having substantially the same average density.

124. Wayne, R.M.; Miexzyslaw, T. 1989. Fiberboard shim, for automotive use containing blocked isocyanate, has improved strength characteristics. Assignee: Eagle Picher Co. Document type: Patent, P.N.: US 4857252 I.D.: 890815.

Summary: Hardened fiberboard shims are manufactured by (1) combining cellulosic fiber, a blocked isocyanate, and water-soluble thermosetting resin to form a pulp furnish; the thermosetting resin has a curing temperature below that of the cure temperature of the blocked isocyanate; (2) forming a fiberboard from the furnish by foaming an uncured sheet, and heating to temperature above the cure temperature of the thermosetting resin and less than the cure temperature of the blocked isocyanate, so curing the thermosetting resin; (3) cutting the fiberboard to form shims; and (4) curing the shims to cause the blocked isocyanate to react with the cellulosic fiber. The fiberboard shims are strong and easy to manufacture without the need for hazardous solvent-based isocyanates.

Dry and Wet Processes (125–130)

125. Clarke, J.T.; Hoffman, M.R.; Luck, A.J. 1981. Product containing high density skins by including urea skin forming chemicals in a compressed fibrous layer on surfaces of fiberboard. Assignee: Masonite Corp. Assignee codes: 52888. Document type: Utility, A.N.: US 95628 (95630), A.D.: 781119 (791119) P.N.: US 4283450 (4305989), I.D.: 810811 (811215).

Summary: A fiberboard is manufactured with relatively high density skins on a relatively low density core by including urea in at least the surface fibers of a consolidated mat, having a density of less than 35 lb/ft^3 (560 kg/m^3), and then hot-pressing the consolidated mat at a temperature of at least 525°F (275°C) to form a board having high density surface skins. The skin on the higher density mats improves the board strength, stiffness, paint hold-out, and design fidelity properties.

126. Kelly, P.B. 1984. Resin bonded hardboard bowling lanes have superior playing surfaces, durability, and wear characteristics. Assignee: General Electric Co., Document type: Patent, P.N.: US 4456253, I.D.: 840626.

Summary: Resin bonded hardboard products have superior surfaces and longer wear than conventional wooden bowling lanes, with reduced damage on impact in ball release and pin deck areas. They can be inserted as a single panel into existing lanes and, if finished on both faces, be turned over to provide a new surface when the first one has become worn. The surfaces have superior resistance to impact, lighted cigarettes, alcohol, detergent, shoe polish, and mustard, compared to polyurethane and nitrocellulose-lacquered bowling lanes.

127. Lee, P. 1988. High tear strength fibre board for shoe sole manufacture is prepared by moulding cotton waste and synthetic fiber blend. (Korea). Assignee: Lee P., Document type: Patent, P.N.: KR 8802136, I.D.: 881017.

(No abstract is available.)

128. Luck, A.J.; Clarke, J.T.; Hoffman, M.R. 1979. Fiberboard with low density core and high density skin formed by impregnating with a skin-forming chemical, e.g., thiourea, acetamide, or diammonum phosphate, and heat-pressing to form skin. Assignee: Masonite Corp. Assignee codes: Document type: Patent, A.N.: A.D.: P.N.: US 4475148 I.D.: 791120.

Summary: A fiberboard product consists of a base layer of cellulosic fibers of density 10 to 35 lb/ft^3 (160 to 560 kg/m^3), and a skin formed on ≥1 face that has a greater density than that of the base layer. The skin is formed by contacting the surface of the fiberboard with 5 to 20 percent weight of a skin-forming chemical and heating to ≥525°F (275°C). The fiberboard is lightweight but has the strength and stiffness properties of a hardboard of density 45 to 65 lb/ft^3 (720 to 1,040 kg/m^3). The board has good design-fidelity and paint hold-out properties and may be used for wall paneling, siding, or moulding.

129. Luck, A.J.; Clarke, J.T.; Hoffman, M.R. 1981. Fiberboard with high-density skin made by whole or partial impregnation with urea before hot-pressing. Assignee: Masonite Corp., Document type: Patent, P.N.: US 4268565, I.D.: 810519.

Summary: Finished board has a hard skin in the weight range 40 to 55 lb/ft^3 (0.64 to 0.88 kg/m^3) and a base portion in the weight range below 35 lb/ft^3 (0.56 kg/m^3); the board is treated with urea in an amount of at least 5 percent weight, preferably 5 to 35 weight percent, before hot pressing at 525°F to 650°F (275°C to 342°C). Preferably, hot pressing is done in a mold for shaping an embossed furniture part resembling natural wood, e.g., a drawer front, with a very hard surface skin.

130. Socha, R.P. 1991. Laminate having high strength—prepared by laminating glass fiber reinforced polyester panel and tempered hardboard substrate with water resistant binder. Assignee: Standard Oil Co. (Ohio), P.N.: AU 9176461, I.D.: US 528674 (900524).

Summary: A laminate consists of a glass fiber reinforced polyester panel attached to a tempered hardboard substrate. The substrate is prepared using a water-resistant binder. The resulting panel exhibits high strength and excellent resistance to moisture. It can be used for exterior walls of recreational vehicles.

Dimensional Stability and Water Resistance

Research

Dry Process (131–153)

131. Anon. 1987. Automation comes to fiberboard's aid. Finishing V. 11(3): 18–19.

Summary: Products such as door facings and panels can be dimensional-stabilized and spray-painted in a new automatic plant by Air Industrial Developments Ltd. Panels can be imparted full dimensional stability in less than a minute by a method of impregnation.

132. Christensen, F.J.; Ellis, M.L. 1954. The suitability of xanthorrhoea resin as a binder for sawdust in the manufacture of hardboard by a dry process. Experiment, U.15-3/2. Melbourne, Australia: Division of Forest Products, C.S.I.R.O. 12 p.

Summary: Even with 20 percent resin, mechanical strength and water resistance of hardboard were considerably less than those of synthetic-resin/sawdust boards produced under comparable conditions.

133. Elkhova, N.N.; Panyukov, A.E. 1973. Heat treatment of hardboard made by the dry method without a binder. Sb. Tr. VNII Derevoobrabat. Prom. 6: 33–40. (Russ. sum.).

Summary: Heat treatment (338°F (170°C)) for 2 to 4 h increased the strength and water resistance of the boards. Static bending strength was increased by 12 percent, while water absorption and swelling were reduced by 30 and 34 percent, respectively. An equalization of the strength and water resistance along the surface of the boards also occurred.

134. Ely, H.M. 1954. Experiments on an accelerated method for determining water absorption of hardboard. Journal of the Forest Products Research Society. 4(2): 85–87.

Summary: A pressure tank filled with water (5 lb/in^2 (34.4 kPa) for 30 min) was used to accelerate the testing of water absorption in hardboard. This produced a correlation curve that may be used for control purposes in the manufacture process. The 6- by 6- in. (2.36- by 2.36-cm) hardboard specimens were also subjected to a 24-h water-soaking test. Both tests showed promising results.

135. Fahey, D.J. 1976. High-frequency pressing of phenolic-bonded hardboards. Forest Products Journal. 26(7): 32–33.

Summary: The high-frequency pressing system presently used with urea-bonded medium-density hardboard was investigated for curing phenolic-bonded boards. More time was required for pressing phenolic-bonded board, but the addition of 10 percent resorcinol to the phenolic system caused the pressing time to approach that for the urea system. The phenolic resorcinol boards had better linear stability, wet strength and stiffness, and durability.

136. Frashour, R.G.; Cooks, W.H.; Morschauser, C.R. 1955. Properties of dry-formed hardboards with various resin contents. Rep. L–5. Corvallis, OR: Oregon Forest Products Laboratory, Oregon State University. 12 p.

Summary: Hardboards were made with steamed Douglas-fir fibers having 0 to 3 percent resin contents and 1 to 1.5 percent wax content which were pressed at 360°F (182°C) and 400°F (204°C) for 45 s at 1,000 lb/in^2 (6.89 MPa), then 9 min and 15 s at 100 lb/in^2 (6.89 kPa). Water absorption decreased, strength increased, but toughness decreased, with an increase in resin content, an increase in density, or an increase in press temperature.

137. Kelly, M.W.; Hart, C.A.; Laughinghouse, G.F. 1984. Water soak versus wicking test for hardboard siding. Forest Products Journal. 34(6): 49–54.

Summary: An exploratory study was conducted to evaluate the applicability of the 24-h water-soak test to hardboard weatherboards. Weatherboards that had failed in service had a much larger quantity of water wicking into the sample than was found for the more recently produced material. It is suggested that entrapped air is responsible for the limited penetration inherent in the 24-h water-soak test.

138. Mal'tseva, T.V.; El'bert, A.A.; Gamova, I.A. 1981. Hardboards made by dry formation using modifying additives. Derevoobrabat. Prom. 1: 11–12. (Russ. sum.).

Summary: A 99.5:0.5 mixture of urea and polyvinyl alcohol was used instead of 5 percent phenol formaldehyde resin for hardboard production. The board was pressed at 356°F to 464°F (180°C to 240°C). Bending strength of boards increased with increasing pressing temperature and increasing amounts of urea added (up to 8 percent). Water absorption and swelling decreased.

139. Myers, G.C. 1977. How fiber acidity affected functional properties of dry-formed hardboards. Res. Pap. FPL 282. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 11 p.

Summary: By adjusting fiber acidity, red oak boards had strength properties comparable to that of balsam fir boards. Boards from various blends of red oak and balsam fir fiber adjusted to a common pH value possessed strengths of comparable values. Linear and thickness stability were more dependent on species than were other properties. Acidity control was found to be beneficial in maintaining board quality.

140. Myers, G.C. 1987. Feasibility of using an ammonium-based lignosulfonate binder system for medium-density hardboard. Forest Products Journal. 37(10): 63–67.

Summary: Lignosulfonate-bonded (ALS) hardboards were lower than phenol formaldehyde resin bonded hardboards in bending modulus of elasticity. The ALS bonds had excellent strength retention after a 24-h water soak, and had greater linear and weight changes than phenol formaldehyde resin bonded boards but less thickness change.

141. Okonov, Z.V.; Done, M.V. 1973. Thermal treatment of hardboards from sawdust. Poluchenie, Sovistva, Primen. Modifits. Drev. 45–50. (Russ. sum.).

Summary: Thermal treatment lowered the equilibrium moisture content of the boards. Thermal treatment at 329°F (165°C) for 4 h or at 347°F (175°C) for 3 h reduced water absorption and swelling of the boards, at the same time increasing their static bending strength 6 to 10 percent. Treatment at 383°F (195°C) for 3 h or 410°F (210°C) for 2 h further lowered water absorption and swelling but reduced bending strength to levels below that of the control boards. Thermal treatment at 347°F to 392°F (175°C to 200°C) for 2 to 4 h can be regarded as optimum.

142. Osawa, K.M.; Moriyama, M.; Endo, H.; Takahashi, H. 1976. Effects of humidifying conditions on physical properties of dry fiberboard. Journal of the Hokkaido Forest Products Research Institute. 1976(4), No. 291: 6–10. (Jap.; Engl. sum.).

Summary: The rate of water absorption, thickness swelling, and roughness of board surface at a constant relative humidity tended to increase with increasing temperature.

143. Ozolinya, I.O. 1984. Possibility of improving hardboard quality by acetylation. Problem Kompleks. Ispol'z. Drev. Syr'ya (Karlivan, V.P. and others, eds.): 309 (1984 Riga). (Russ. sum.).

Summary: The moisture resistance and biological resistance of hardboards were increased by treating the wood fibers with acetic anhydride at 176°F to 257°F (80°C to 125°C) for 1 to 10 h followed by drying at 221°F (105°C).

144. Rowell, R.M. 1987. Can the cell wall be stabilized? Wood science seminar 1: Stabilization of the wood cell wall. East Lansing, MI: Michigan State University: 53–64.

Summary: Three methods of stabilizing the cell wall were discussed: (a) stabilizing the cell wall matrix in such a way as to restrain the cell wall polymers from swelling, (b) reducing the hydroscopicity of the cell wall polymers so they do not attract as much moisture, and (c) bulking the cell wall polymers to maintain the green or wet volume so moisture does not cause additional swelling to occur. Bulking the cell wall with a water-soluble phenol-formaldehyde solution followed by polymerization reduced hydroscopicity and swelled the cell wall to its green volume. The amount of swelling increased as the amount of impregnated resin was reduced. The authors conclude that neither cell wall matrix fixation, reducing hydroscopicity of cell wall polymers, nor bulking the cell wall alone results in complete stabilization of the cell wall to change moisture content.

145. Rowell, R.M.; Rowell, J.S. 1988. Moisture sorption properties of acetylated lignocellulosic fibers. Proceedings of the 10th cellulose conference; 1988 May 29–June 2; Syracuse, NY. New York: Wiley and Sons, Inc.: 343–355.

Summary: All types of acetylated lignocellulosic materials showed a similar pattern in reducing moisture sorption as a function of acetyl content. These materials varied widely in their lignin, hemicellulose, and cellulose content. Acetylation may control moisture sorption in the accessible lignin and hemicellulose polymers of the cell wall but may not greatly affect cellulose sorption.

146. Rowell, R.M.; Keany, F.M. 1991. Fiberboard made from acetylated bagasse fiber. Wood and Fiber Science. 23(1): 15–22.

Summary: Acetylation of bagasse fiber produced a more hydrophobic fiber whose equilibrium moisture content was significantly reduced as compared with untreated fiber. Fiberboards made from acetylated fiber showed greatly reduced rate and extent of thickness swelling, and greatly reduced irreversible and reversible swelling compared to control boards. However, mechanical properties of both control and acetylated boards were approximately the same. Any differences may have been due to the distribution of fines in both types of boards.

147. Steinmetz, P.E. 1970. How press temperature affects linear stability of hardboard. Wood Products Journal. 75(6): 49.

Summary: Increases in the pressing temperature reduced the linear movement of boards exposed for 30 days to relative humidities of 65 percent, 80 percent, and 90 percent, or to a water soak. Increased pressing temperature also reduced the press cycle time; pressing time was reduced by 70 percent by pressing at 500°F (260°C) instead of 383°F (195°C).

148. Steinmetz, P.E. 1977. Resin systems and glass reinforcements to improve dry-formed hardboards. Res. Pap. FPL–284. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 11 p.

Summary: On an equal-cost basis, dry strength and stiffness, thickness swell, and water absorption were improved with the thermoplastic resin. Wet properties and linear stability, however, were not as satisfactory. Glass yarn scrim pretreated with phenolic resin and bonded to each side of a hardboard mat was highly effective, especially in reducing board linear movement.

149. Suzuki, H.; Takahashi, H.; Endoh, K. 1976. On water absorbability of dry process fiberboard. Journal of the Japanese Wood Research Society. 22(10): 557–563.

Summary: Water absorption and swelling in thickness decreased with increasing addition of resin or paraffin wax to the board. Addition of both resin and paraffin wax resulted in lower water absorption than that due to paraffin wax alone. At longer periods of immersion in water, the effect of paraffin wax gradually decreased.

150. Vershina, V.S.; Laskeev, P.K. 1967. Chemical changes in groundwood during the manufacture of structural fiberboards by the dry process. Mater. Nauch.–Tekh. Konf. Leningrad. Lesotekh. Akad., Part 1: 113–115. (Russ. sum.).

Summary: With increasing steaming time, the mechanical strength of the boards decreased, while its water resistance increased. The optimum conditions for boards, satisfying standard quality requirements, were a steaming temperature of 356°F to 365°F (180°C to185°C) and a steaming time of 3 min.

151. Ziedin'sh, I.O.; Lielpeteris, U. Ya. 1975. Optimization of hardboard manufacture from modified pine sawdust using statistical methods. Khim. Modif. Drev. 5–11. (Russ. sum.).

Summary: Compared to the binder alone, the addition of binder and ammonia significantly

improved the properties of hardboards, especially their water absorption and swelling. From the viewpoint of hardboard properties, the addition of ammonia without the binder is equivalent to the addition of about 2.5 percent of the binder. The addition of ammonia and 1.2 to 1.3 percent binder is equivalent to 5 percent of the binder.

152. Ziedien'sh, I.O.; Lielpeteris, U. Ya.; Pel'nya, K.S. 1977. Improving the physical and mechanical properties of hardboards from pine sawdust without use of a binder. Mezhvuz. Sb., Ser. Tekhnol. Drev. Plit. Plastikov. 4: 37–45. (Russ. sum.).

Summary: The combined addition of formaldehyde and ammonia considerably increased the static bending strength and water resistance of the board. Up to 0.3 percent ammonium chloride could be added, which increased moisture resistance and only slightly reduced static bending strength. Compared to conventional boards from pine sawdust, the addition of formaldehyde, ammonia, and up to 0.3 percent ammonium chloride reduced water absorption and swelling two- to threefold.

153. Ziedin'sh, I .O.; Lielpeteris, U. Ya.; Listvin, A.V. 1978. Physical and mechanical properties and manufacturing parameters of fiberboards from modified fibers. Tekhnol. Modif. Drev.: 13–24. (Russ. sum.).

Summary: Modification of fibers with ammonia considerably improved board properties; e.g., static bending strength increased 1. 2 to 6.2 times to 11.6 to 13 x 10^3 lb/in^2 (80 to 90 MPa) and swelling decreased 1.4 to 2.2 times. The effect of addition of ammonia (4.6 to 5.7 percent) on static bending strength was equivalent to that of 3 to 4.5 percent phenyl-formaldehyde binder. The boards obtained from the modified fibers (containing no additives and without thermal treatment) considerably exceeded the standard for static bending strength of hardboards and had satisfactory water absorption.

(Also see references 1, 7, 10, 33–36, 41, 42, 44–48, and 255.)

Wet Process (154–204)

154. Broeker, F.W.; Weissmann, G. 1989. Oil hardening of hard-wood fiberboards. Holz als Roh- und Werkstoff. 47(1): 33. (Ger. sum.).

Summary: Treatment of fiberboard with hot (194°F (90°C)) vegetable oil (sunflower, tung, or castor oil) followed by oven drying (302°F (150°C)) improved board thickness swelling, water absorption, and bending properties.

155. Bucko, J.; Vacek, J. 1978. Effect of pressing on the quality and quantity of fiberboard manufactured using the wet process. Drevo. 33(2): 43–45, 51. (Slovak. sum.).

Summary: The boards produced at 446°F (230°C) using a shorter pressing cycle, showed somewhat lower swelling and improved bending and z-directional strength than those produced at 428°F (220°C). Authors recommend using the shorter cycle at 446°F (230°C) rather than the regular cycle at 428°F (220°C). The shorter pressing cycle can increase production up to 15 percent.

156. Caulfield, D.F. 1987. Dimensional stability of paper: papermaking methods and stabilization of cell walls. Wood science seminar 1: Stabilization of the wood cell wall. East Lansing, MI: Michigan State University: 87–98.

Summary: A certain measure of control of dimensional stability can be achieved using conventional papermaking practices. However, these conventional methods rely largely on affecting how the swelling of the cell wall is transmitted through the paper's structure of fibers, voids, and interfiber bonds. These conventional methods are rather limited in their effectiveness because they do not tackle the root cause of paper's inherent dimensional instability, the swelling and instability of the cell wall. If, on the other hand, dimensional stability of paper is modified by changing the swelling of the cell wall, greater levels of control can be achieved. An additional benefit may also result in terms of increased wet-stiffness.

157. Coda, R.L. 1978. Water reuse in a wet-process hardboard manufacturing plant. U.S. Environmental Protection Agency 600/2–78–150: 55 p.

Summary: Linear expansion of the board increased after the closing of the process (water reuse). Some drawbacks of the closed system are a darker board and overall reduced cleanliness of the mill.

158. Currier, R.A. 1957. Effect of cyclic humidification on dimensional stability of commercial hardboard. Forest Products Journal. 7(3): 95–100.

Summary: The study determined the effect of cycling relative humidity conditions on dimensional stability of hardboard. Standard 1/8- and 1/4-in. (3.17- and 6.35-mm) specimens were subjected to 12 cycles of 30 to 90 to 30 percent relative humidity. Weight, thickness, and linear expansion were determined after conditioning at 30 percent relative humidity, and families of typical curves depicting the changes were constructed.

159. Dallons, V. 1979. In-plant pollution control in the hardboard industry. Forest Products Journal. 29(10): 70–74.

Summary: Complete white water recycling can cause loss of board strength, sticking in the press, increased water absorption, decreased dimensional stability, and darker boards. Decreased dimensional stability and increased water absorption are due to high white water solids concentrations, which are related to the amount of wood material dissolved during refining, the amount of process water recycled, the degree of pulp washing practiced, and the use of wet–wet or wet–dry processing.

160. Dhamaney, C.P.; Jauhori, A.N. 1976. Studies on hardboard preparation. (3) Nagaland forest waste for hardboard tea chests. Indian Pulp and Paper. 31(2): 3–4.

Summary: Oil-tempered, retempered (302°F (150°C) for 3 h), and veneered hardboards from cellulosic waste materials were used to produce tea chests. Retempering improved the strength properties and water absorption of the boards. Tea chests prepared from the retempered and veneered board met the Indian standard for corner drop and end compression.

161. Dosoudil, A. 1960. Further investigation on the absorption of water in fiberboard, especially hardboard. Holz als Roh- und Werkstoff. 18(3): 106–111. (Ger. sum.).

Summary: This study investigated water absorption and thickness swelling with increasing temperature of water, decreasing water absorption in relation to sample size and edge protection, time of increase for water absorption and thickness swelling, behavior of samples after storage in water, and amount of thickness swelling resulting from storage in water or humid air on condition that samples contained an equal quantity of water. Finally, linear expansion was determined for German hardboard. The effect of varying test conditions was considerably less important for thickness swelling than for water absorption.

162. Fadl, N.A.; Rakha, M. 1984. Influence of pH of phenol-formaldehyde resin and thermal treatments on the properties of hardboard. Holz als Roh- und Werkstoff. 42(2): 59–62. (Ger. sum.).

Summary: Rice straw hardboard properties improved with increasing hydrogen ion concentration up to a certain pH (3.3 and 5). However, higher hydrogen ion concentration caused damage of cellulose fibers, thereby deteriorating strength properties. With thermal treatment, a greater improvement was attained at lower hydrogen ion concentrations than without treatment. This may be due to the catalyzing of the self-cross-linking cellulose and hemicellulose chains, which reduce the swelling ability of finished hardboards.

163. Forest Industries. 1981. Waste water discharge cut in hardboard plant. Forest Industries. 107(11): 54.

Summary: Use of a closed white water system resulted in a reduction of water discharge. To achieve satisfactory water-absorption control, slack wax sizing was replaced by Mobil Oil Corporation's Mobilcer 46, which is a cationic, acid-sensitive emulsion capable of forming a tight bond with wood.

164. Gavrilidin, E.A.; Puzyrev, S.A.; Krechetova, S.P. 1978. Petroleum resin for sizing fiberboards. Tsellyuloza, Bumagz, Karton Ref. Inform. 15: 13–14. (Russ. sum.).

Summary: A paper-sizing agent based on unmodified petroleum resin emulsified with saponified resin acids or synthetic fatty acid soaps was successfully adapted for sizing wet-process hardboards. The advantage of using the petroleum resin emulsion instead of a paraffin emulsion is an increase in board strength in addition to water repellency.

165. Gavrilidin, E.A.; Puzyrev, S.A.; Krechetova, S.P. 1982. Frequency of recycling white water and its effect on sizing of fiberboards with polymetric petroleum resins. Sb. Tr. VNIIB, Issled. Oblasti Tekhnol. Bumagi Kartona (Novikov, N.E., ed.): 49–54. (Russ. sum.).

Summary: Sizing was conducted with polymeric petroleum resin dispersion as the sizing agent and aluminum sulfate or sulfuric acid as the coagulant. Results showed that partial or complete closure of the water cycle yields fiberboard with sufficient strength and moisture resistance, even when using 100 percent hardwoods and sulfuric acid as the coagulant. Consumption of the resin dispersion should not be lower than 2 percent.

166. Giebeler, E. 1983. Dimensional stabilization of wood by moisture heat pressure treatment. Holz als Roh- und Werkstoff. 41(3): 87–94. (Ger. sum.).

Summary: Dimensional stabilization of 0.16-in.-(4-mm-) thick hardboard was determined after it had been heat treated at 356°F to 392°F (180°C to 200°C) within an inert gas atmosphere of 8 to 10 bar (116 to 145 lb/in^2) (451 to 564 kPa) for 1 to 4 h in an autoclave. The moisture content of the hardboard was less than 10 percent. Examples of this heat pressure treatment of hardboard showed reduction in thickness swelling of almost 60 percent, and an increase in resistance against fungi and

insects as well as an increase in modulus of elasticity in bending. The operation has also proved to be economical.

167. Gluhkov, V.I.; Sutyagina, S.E.; Raichuk, F.Z. 1984. Manufacture and properties of high-density hardboard. Problemy kompleks. Ispol'z. Drev. Syr'ya (Karlivan, V.P., and others, eds.): 275–276. (Russ. sum.).

Summary: Impregnation of hardboards (density of 53 to 59 lb/ft^3 (850 to 950 kg/ m^3) with 22 to 35 percent methyl methacrylate reduced water and moisture absorption and increased strength and resistance to ultraviolet light and cyclic freezing and thawing.

168. Gromova, N.A.; Liptsev, N.V. 1979. Study of interaction of resorcinol with wood carbohydrates in hydrothermal treatment and grinding in the manufacture of hardboards. Khim. Mekh. Pererab. Drev., Drev. Otkhodov 5: 40–44. (Russ. sum.).

Summary: Resorcinol added during hydrothermal treatment and grinding of birchwood chips not only inhibited the degradation of carbohydrates but also interacted with them. The interaction of resorcinol with wood carbohydrates may involve paramagnetic centers formed during thermal and mechanical degradation of polymers, carboxyl groups, and thermal aldehyde or hydroxide groups.

169. Gromova, N.A; Liptsev, N.V.; Kutnevich, A.M.; Solechnik, N.Ya. 1976. Reaction of polyvinyl alcohol with lignin in the manufacture of extra hard fiberboards. Mezhvuz. Sb. Nauch. Tr. Ser. Khim. Mekh. Pererabotka Drev., Drev. Otkhodov 2: 84–87. (Russ. sum.).

Summary: Two possible mechanisms of reaction of lignin with polyvinyl alcohol are suggested: binding of polyvinyl alcohol by the paramagnetic centers of lignin or polymerization at double bonds. Compared to conventional hardboards, the hardboards containing modified lignin had higher static bending strength and lower water absorption (14.8 versus 25.9 percent) and swelling (9.5 versus 17.5 percent).

170. Holokiz, H. 1973. Effect of drainage time on the properties of eucalypt hardboard. Appita. 26(6): 437–443.

Summary: The dimensional stability of a hardboard made from *Eucalyptus maculate* (which has a high density) improved as the drainage time increased, but the opposite effect was found in the case of boards made from low density *Eucalyptus obliqua*. Paint hold-out and resistance to fiber raising and moisture usually improved with increased drainage time. Evidently, the drainage time testing method can be used as an effective tool in evaluating eucalypt pulps used in producing hardboards.

171. Jansson, M. 1982. Hardboard quality when produced in closed white water systems. Forest Products Journal. 32(6): 39–46.

Summary: Hardboards were formed using white water with concentrations from 0.2 to 9.0 percent dissolved solids. Increasing white water concentrations reduced thickness swelling and equilibrium moisture content of the hardboards, thereby improving dimensional stability. On the other hand, increasing white water concentration resulted in increased water absorption, which produced stains and bleeding in painted boards. Also, it promoted fungal growth and darkened board surfaces.

172. Johns, W.E.; Woo, J.K. 1978. Surface treatment for high density fiberboard. Forest Products Journal. 28(5): 42–48.

Summary: Unpressed fiberboard "blanks" were sprayed with (a) H_20_2, (b) $H_20_2 + HNO_3$, (c) H_20_2 + furfuryl alcohol, (d) H_20_2 + furfuryl alcohol + HNO_3, or (e) H_20_2 + maleic acid. Treatment (e) gave the largest values for modulus of rupture and tensile strength and the smallest values for water absorption and thickness swell, in comparison with untreated controls. Water absorption was increased by all treatments except (b).

173. Johnson, J.W. 1956. Dimensional changes in hardboard from soaking and high humidity. Rep. T–16. Corvallis, OR: Oregon Forest Products Laboratory. 24 p.

Summary: Straight-line relationships between percentages of water absorption and thickness swelling were found to exist for most boards subjected to the 24-h soak test; all the boards absorbed water at about the same rate, provided the rates of absorption were based on percentages of total water absorbed; within 10 days after exposure to high relative humidity conditions, most boards had reached about the same moisture content; the water absorbed was about 85 percent of that taken up during 8 months exposure.

174. Khan, M.S.; Shafi, M. 1988. Effects of chemical pretreatment of sundri wood chips in making hardboard. Chittagong, Bangledesh: Bano biggyan Patrika: 17(1–2): 1–7.

Summary: Boards made from chips pretreated with sodium hydroxide or along with sodium sulfite were stronger than those made from chips that had been only steam softened. All the pretreatment methods increased water absorption compared to simply steaming for 1 h.

175. Klinga, L.O.; Tarkow, H. 1966. Dimensional stabilization of hardboard by acetylation. Tappi. 49(1): 23–27.

Summary: Acetylation after board formation resulted in a reduction of the equilibrium moisture content and a pronounced expansion in thickness as well as some expansion in the plane of the sheet. With 5 percent acetyl content in the Masonite board, the dimensional range in the plane of the sheet between 30 and 90 percent relative humidity was reduced about 23 percent, and between 65 and 100 percent relative humidity about 34 percent. The corresponding reductions in thickness were 20 and 42 percent. For the Asplund board, the relative reductions in these dimensional ranges were generally lower, while the absolute reductions were about the same as for the Masonite board. The increase in dimensional stability was accompanied by a slight increase in tensile strength, amounting to 7 to 10 percent at 5 percent acetyl content. Surface roughness was slightly increased.

176. Kloot, N.H.; Walker, V.Y. 1951. The mechanical properties of fiber building boards. Sub-project T.M. 26–0. Miscellaneous tests. Progress Report 4. The effect of soaking on some properties of fiberboards. Division of Forest Products, C.S.I.R.O.: 11.

Summary: Hardboard and insulating board were tested for bending properties and puncture resistance after soaking in water. The relationship between the bending properties and soaking period up to 24 h was sufficiently close to exponential. Soaking appeared to have different effects on the puncture resistance of the two types of boards.

177. Krasnova, O.M.; Uzlov, G.A.; Zhukova, I.P.; Tsarev, G.I.; Shevchenko, V.S. 1987. Use of tall oil from hardwoods in manufacture of hardboard. Gidroliz. lesokhim. Prom. 4: 17018. (Russ. sum.).

Summary: Studies showed that thermally treated hardwood tall oil can be used as a strengthening and waterproofing additive in the manufacture of high-density hardboards. Industrial studies confirmed that treated tall oil can be used in surface impregnation to obtain high-density hardboard (>59 lb/ft^3 (>950 kg/ m^3)) with satisfactory properties.

178. Kuroki, Y.; Tanahashi, N. 1963. Study on the oil tempering of hardboard. I. On the relation between quality of hardboard and fraction of tall oil. Journal of the Japanese Wood Research Society. 9(2): 49–52.

Summary: The effects of various fractions of distilled tall oil on the quality of hardboard was examined. The pitch (resin-acid) fraction was found to improve bending strength and water repellency appreciably. The higher temperatures and longer duration of heat treatment tended to give highest strength and water-repellency values.

179. Kuroki, Y.; Tanahashi, N. 1963. Study on the oil tempering of hardboard. Part II. Influence of the fatty acids and its esters in tall oil on the quality of hardboard. Journal of the Japanese Wood Research Society. 9(3): 114–118.

Summary: The study examined the effects of linoleic, linolenic, and oleic acids (and esters) on the modulus of rupture and water absorption of hardboards during hot pressing. Board quality was considerably improved by linoleic and linolenic acids but only slightly improved by oleic acid.

180. Lampert, H. 1967. Observations on some technological possibilities for important physical properties of hardboards. Holztechnologie. 8(3): 172–176. (Ger.; Russ.; Engl. sum.).

Summary: The cellulose content of the raw material was primarily responsible for tensile and bending strength. The hemicelluloses can serve as binder, but also affect swelling properties adversely. A high lignin content reduced swelling of hardboards.

181. Lundgren, A. 1958. Hygroscopical properties of fiberboard. Holz als Roh- und Werkstoff. 16(4): 122–127. (Ger. sum.).

Summary: The dimensional changes of hardboard material occurring during every wetting cycle are irreversible. Hardboard can never regain a special hygroscopical value of equilibrium. These irreversible dimensional changes are smaller than the reversible changes but they cause the main problems in actual use. Through inter-Scandanavian collaboration, a thorough investigation was carried out to prepare new specifications for hardboard testing, which will also give the public reliable information about the properties of the material.

182. Millet, M.A.; Hohf, J.P. 1948. Dimensional stability of synthetic board materials used as core stock. Proceedings, Forest Products Research Society conference, Madison, WI: 280–288.

Summary: Panels of wet-process hardboard corestock with plywood and veneer faces were evaluated on the basis of both swelling and recovery data, following cyclic exposure to high and low relative humidity conditions. Results indicate that in the ranges studied, neither fiber size nor fiber-binder ratio had any noticeable effect on the stability of the core stock. Drying-oil treatment was of considerable benefit in increasing the bending strength of fibrous core materials and greatly

reduced the extent of springback or recovery following water immersion. It had little effect on swelling equilibrium, whether by water immersion or by exposure to high relative humidities, but did retard the rate of swelling.

183. Myers, G.C. 1982. Response of experimental hardboard dimensions and weight to cyclic relative humidity. Forest Products Journal. 32(7): 41–44.

Summary: Most hardboards followed a consistent pattern of increasing dimensions and weight on the absorption cycle and decreasing on the desorption cycle but no two boards had identical responses. Not enough replications were used to establish any significant difference between manufacturing variables.

184. Ogland, M.J. 1948. Hot air treatment of hardboard. Norsk Skogind. 2: 301–305.

Summary: Heat treatment of hardboard at temperatures above 320°F (160°C) gives higher bending strength, lower water absorption, and lower swelling tendency in damp air and water than at lower temperatures; the treatment is also more rapid and less costly. The effect of the heat treatment seems to be due to a change in the properties of the hemicellulose.

185. Pawlicki, J. 1985. Studies on the effect of formaldehyde on the physical properties of wood-based fiberboards. Holzforschung und Holzverwertung. 37(6): 112–114. (Ger.; Engl. sum.).

Summary: Pine fiberboards were prepared with formalin or paraformaldehyde, with or without the addition of ammonia. The treatments improved the mechanical properties of the boards and decreased thickness swelling and water absorption. Paraformaldehyde gave better results than formalin.

186. Papier and Kunststoff–Verarbeiter. 1971. Testing of solid-fiber board: water absorption and thickness swelling (water storage). Papierverarbeiter. 6(6): 20–21 (Ger. sum.).

(This abstract is not available.)

187. Pecina, H. 1981. Chemical modification of the basic components of wood. (2) Changes in the properties of binder-free hardboards from chemical modified pulp. Holztechnologie. 22(3): 148–154. (Ger.; Russ.; Engl. sum.).

Summary: The hydrothermal treatment before (and during) pulping had a great effect on the mechanical and hygroscopical properties of the boards.

188. Piiparinen, L.I. 1977. Influence of drying conditions on the thickness dimensional stability of low-density fiberboard. University of Minnesota. Ph.D. thesis. 63 p.

Summary: Fiberboard thickness expanded immediately from the wet-pressed condition and reached its maximum after 20 min of drying at temperatures ranging from 212°F to 383°F (100°C to 195°C). This expansion was due to a reduction in the surface tension of water with an increase in temperature. Irreversible thickness swelling decreased with an increase in drying temperature. A part of the swelling decrease was attributed to a decrease in the internal stress level and the concurrent expansion during the first 20 min of drying, which otherwise would express itself as irreversible thickness swelling during subsequent water soaking.

189. Po, Z.Y. 1981. Rapid determination of water absorption of fiberboard. Industry of Forestry Products (Linchan Gongye). (Jilin Institute of Forestry, Jilin, China). 5: 22–24. (Chin. sum.).

Summary: Effects of immersion time and water temperature on water absorption were determined after 2, 4, and 24 h. Results showed that the water absorption was low at the beginning of immersion, increased rapidly up to 16 h, and then slowed down. A regression equation was established for quick calculation of water absorption.

190. Schaudy, R.; Proksch, E. 1980. Electron-beam curing of wood-particle boards and hardboards impregnated with synthetic resins. Holzforschung. 34(3): 104–109. (Ger.; Engl. sum.).

Summary: Wood-particle boards and fiber building boards (hardboards) impregnated with synthetic resins were cured by using an electron accelerator. Of a number of resin–monomer mixtures, the two most suitable were styrene-free polyester and acrylic-modified melamine resin. The radiation-cured boards showed increased hardness and reduced swelling, but only moderate weather resistance.

191. Schaudy, R.; Proksch, E.; Slais, E. 1976. Gamma-radiation curing particle boards and fiberboards impregnated with synthetic resins. Ber. Oesterr. Studienges. Atomenergie 1569: 16 p. (Ger. sum.).

Summary: The impregnated and gamma-irradiated boards showed markedly increased hardness and improved dimensional stability when stored under water.

192. Schaudy, R.; Proksch, E. 1976. Gamma-radiation hardening of synthetic resin-impregnated particle boards and hardboards. Holzforschung. 30(5): 164–171. (Ger.; Engl. sum.).

Summary: The condition for rapid and complete impregnation of wood-particle boards and hardboards with unsaturated polyester resin was investigated. A mixture containing cobalt naphthenate and benzoin methyl ether yielded the best results. The impregnated and gamma-irradiated boards showed markedly increased hardness and decreased volume swelling (dimensional stability) upon storage under water.

193. Sinclair, G.D. 1964. Fatty acid sizing of hardboards. Tappi. 47(9): 579–584.

Summary: Fatty acids will react with cellulose fiber and partially prevent the sorption of liquid water. This study showed that hard-pressed fiberboards could be waterproofed by adding long-chain fatty acids to the board stock. The short-chain fatty acids C12–C16 were not effective, but an indication of sizing was apparent when long-chain acids C18–C22 were used. Hardboards made by the wet process having no sizing agent sorbed about 50 percent by weight of water in 2 h. When 1 percent behenic acid was added to the pulp stock, the water sorption was reduced to 7 percent. When phenol-formaldehyde, behenic acid, and alum were used, hardboards had very good strength properties with water sorptions as low as 3.7 percent (2-h submersion) or 12 percent (24-h submersion). The long-chain fatty acids were effective for sizing hardboards made from popular pulp, which were difficult to size with wax emulsions.

194. Smirnov, V.N. 1973. Statics of hardboard tempering. Derevoobrabat. Prom. 7: 9–10. (Russ. sum.).

Summary: Equations were derived that describe the steady-state behavior of the tempering chamber and the effects that tempering time, temperature, and the circulation rate have on the properties of hardboard. By using the derived equations for optimizing the operating conditions of the tempering chamber, the maximum relative deviations of strength, water absorption, and swelling were reduced to 4.5, 1.3, and 5.6 percent, respectively.

195. Steinmetz, P.E.; Fahey, D.J. 1968. Resin treatments for improving dimensional stability of structural fiberboard. Forest Products Journal. 18(9): 71–75.

Summary: Application of water-soluble phenolic resin in varying amounts to the surface of wet mats produced dimensionally stable boards as well as increased the flexural strength of the board. Powdered phenolic resin added to the pulp also increased the dimensional stability of the boards. A powdered hydrocarbon resin was not as effective as phenolic resins.

196. Steinmetz, P.E.; Fahey, D.J. 1971. Effect of manufacturing variables on stability and strength of wet-formed hardboards. Res. Pap. FPL 142. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 9 p.

Summary: Wood species was the most important factor in increasing dimensional stability; the stability of Douglas-fir boards was greater than that of aspen boards. Pressing temperature and refining method used for processing the asplund fiber also influenced the dimensional stability. Type of resin was the most important factor in deriving high strength and stiff boards.

197. Stemberger, A.; Proson, M. 1977. Determination of water absorption and thickness swelling in hardboard. Les, Yugoslavia. 19(1/2): 15–18, 21. (Slovenijales–LKI Lesonit, 66150 Ilirska Bistrica, Yugoslavia). (Slav.; Engl.; Ger. sum.).

Summary: Data are presented for Yugoslavian wet-process board immersed in water at 68°F to 122°F (20°C to 50°C) for 2 to 24 h. A rapid test method is recommended for process control, based on the linear regression of the water absorption after 24 h at 68°F (20°C) and after 2 h at 122°F (50°C).

198. Suchsland, O. 1965. Swelling stress and swelling deformation in hardboard. [city unknown], MI: Michigan State University Agricultural Experiment Station. Quarterly Bulletin. 47(4): 591–605.

Summary: A special device was made to measure the swelling stress and swelling strain of commercial hardboard. Using this device, dimensional stability of hardboard specimens can be determined.

199. Sudo, K. 1979. Character of hardboards from acetylated asplund pulp. Journal of the Japanese Wood Research Society. 25 (3): 203–208. (Engl.; Jap. sum.).

Summary: Acetylation of the pulp caused a pronounced thickness expansion, regardless of subsequent sizing treatment, and reduced both water absorption and thickness swelling. Hardboards containing over 20 percent acetyl groups showed less than 7 percent thickness swelling and less than 20 percent water absorption when treated with phenolic resin plus paraffin wax.

200. Sukhaya, T.V. 1988. Increasing the quality of hardboard by mild hydrolysis of hardboard suspension. Izv. VUZ, Lesnoi Zh. (Belorussian Technological Institute, USSR). 3: 80–84. (Russ. sum.).

Summary: Birch chips were treated for 1-1/2 h at room temperature with peracetic acid (1 to 15 percent) prior to steaming and defibering. The

treatment reduced the lignin content and increased the content of extractive. Treatment with 15 percent solution reduced water absorption and thickness swelling 100 percent and improved the strength property of the wet-process hardboard. Steaming the birch chips with a 0.5 percent peracetic acid solution prior to defibration yielded hardboard with reduced water sorption and better strength properties. It also increased the defibration rate and permitted a reduction in the steaming temperature by 68°F (20°C).

201. Takamura, N. 1968. Studies on hot pressing and drying processes in the production of fiberboard (6). Relating the modulus of rupture and water absorption to the specific gravity of board. Journal of the Japanese Wood Research Society. 14(7): 363–367. (Engl.; Jap. sum.).

Summary: The exponential relation of water absorption to board density may be attributed to the springback (elasticity) of the board structure, due to relief of compressive internal stresses and cleavage of interfiber bonds during moisture sorption.

202. Wellwood, E.W. 1954. Effect of paint sealer on buckling tendencies of hardboard siding. Journal of the Forest Products Research Society. 4(6): 15–A.

Summary: Face-sealed panels exhibited less tendency to buckle than nontreated ones, the difference becoming less significant with increasing time of exposure and amounts of moisture.

203. Zamyshlyaeva, A.M.; Dmitrieva, G.A. 1966. The use of gossypol resin for the production of extra hard fiberboards. Derevoobrabat. Prom. 15(12): 24–25. (Russ. sum.).

Summary: Results indicated that the optimum temperature of impregnation is 248°F to 266°F (120°C to 130°C), followed by 3 h thermal treatment of the boards at 356°F (180°C). Boards containing 9 to 14 percent gossypol resin had 24-h water absorption of 5.5 to 9 percent. No difficulty was experienced in finishing by conventional methods.

204. Zhang, G.; Yin, S.; Wang, W.; Xu, R.; Cheng, G. 1981. Effects of fiber acetylation on properties of hardboard. Journal of Nanjing Technology College of Forest Products. 3: 70–75. (Chin. sum.).

Summary: The acetylation of pulp expanded the thickness of the hardboard, reduced swelling and absorption of water, increased dimensional stability, and had no significant effect on dry bending strength.

(Also see references 12, 52–55, 58, 59, 66, 67, 72, 74, 78, 104, and 261–266.)

Dry and Wet Processes (205–229)

205. Back, E.L. 1986. Bonding mechanism in hardboard manufacture—a summary. IUFRO 18th World Congress (Ljubljiana) 5: 511–524.

Summary: Hydrogen bonding at lignin and cellulose surfaces is the main type of bonding in hardboard. Moisture resistance, such as wet strength and dimensional stability, developed in the later part of hot press-drying and in dry heat treatment, is caused by formation of covalent interfiber bonds. Unsaturated oils or fats in an oil-tempering process can produce additional crosslinking, but oils prevent hydrogen bonding between fibers in the press-drying operation, in this case reducing board strength.

206. Donvhev, G.; Tsolov, V. 1978. Investigation on the change in water absorption and swelling of hardboards made from conifer fibers in relation to sample size and water temperature. Nauchni Trudove, Vissh Lesotekhnicheski Institut, Sofia (Mekhanichna Tekhnologiya na Drvestinta) (Vissh Lesotekh. Inst., Sofia, Bulgaria). 23: 25–31.

Summary: With samples of 0.79 by 0.79 in. (20 by 20 mm) and 3.94 by 3.94 in. (100 by 100 mm), significant differences occurred in water absorption and thickness swelling results after 2 h and 24 h of water-soak test.

207. Dosoudil, A. 1960. Further investigation on the absorption of water in fiberboard especially fiber hardboard. Holz als Roh- und Werkstoff. 18(3): 106–111. (Ger.; Engl. sum.).

Summary: The investigation was mainly concerned with water absorption and thickness swelling with increasing temperature of water, decreasing water absorption in relation to the size of samples and to edge protection, time of increase for water absorption and thickness swelling, and behavior of samples after storage in water or humid air on condition that sample contained equal quantity of water. Linear expansion was determined for German board. Results showed that the effect of varying test conditions was considerably less important for thickness swelling than for absorption of water.

208. Dube, H.; Kehr, E. 1989. Properties of thin fiberboards and particle boards—thickness swelling, bending and breaking behavior under conditions of use, and puncture resistance. Holztechnologie. 30(4): 203–207.

Summary: The relation between the thickness swelling of thin fiberboards and particleboards was determined for small and large specimens after

water storage for 2 and 24 h. Also presented are experimental results on the creep behavior of drawer bottoms and the puncture resistance of thin particleboards in compression with conventional hardboards.

209. Fraipont, L. 1973. The behavior of hardboard during long-term immersion in water at 20°C. Rapport d'Activite 1972, Station de Technologie Forestiere, Gembloux, Belgium. 135–169. (Fr.; Engl. sum.).

Summary: In conclusion of earlier tests in 1969, 22 different types of hardboard were immersed in water at 68°F (20°C) and then reconditioned for 28 days in air at 68°F (20°C) and 65 percent relative humidity. Details are given of changes in the weight and thickness of the boards during the tests.

210. Fraipont, L. 1973. Behavior of fiberboards in air at various humidities (continued). Rapport d'Activite 1972, Station de Technologie Forestiere, Gembloux, Belgium. 173–207. (Fr.; Engl. sum.).

Summary: Results of tests on the dimensional stability of an additional 11 types of fiberboard are given.

211. Fraipont, L. 1973. Effects of heat treatment on the physical and mechanical properties and behavior of standard hardboard when immersed in water and exposed to air at various humidities. Rapport d'Activite 1972, Station de Technologie Forestiere, Gembloux, Belgium. 211–267. (Fr.; Engl. sum.).

Summary: Detailed results of further tests on the effects of heat treatment on the dimensional stability of fiberboards are provided. The boards in this case were standard types of hardboard.

212. Heebink, B.G. 1972. Irreversible dimensional changes in panel materials. Forest Products Journal. 22(5): 44–48.

Summary: Materials commonly used in composite panels for face, back, or core were exposed to selected equilibrium conditions higher and lower than 42 percent, the original and reconditioning relative humidity. Some materials lengthened while others shortened or remained the same. Panels assembled with 1/16-in. (1.59-mm) decorative laminate on face and back of 1/8-in. (3.17-mm) hardboard core exhibited warping tendencies. However, the test panels were exceedingly thin and warping may be unimportant in panels of a typical thickness such as 3/4 in. (19.05 mm).

213. Hsu, W.E. 1987. Steam pretreatment of wood fibers. Wood Science seminar 1: Stabilization of the wood cell wall. East Lansing, MI: Michigan State University: 65–71.

Summary: Proper steam pretreatment of wood fibers was a very effective way to produce dimensionally stable fiberboards made with either softwood or hardwood furnish and manufactured by either dry or wet processes. In most cases, a proper steam pretreatment not only improved dimensional stability, but also improved mechanical properties.

214. Iosifov, N.; Dinkov, B. 1980. Investigation of the coefficient of linear expansion of hardboards during thermal treatment. Nauchni Trudove, Vissh lesotekhnichski Institut, Sofiya (Makhanichna Tekhnologiya na D'rvesinata) 26: 109–112. (Bulg.; Russ.; Ger. sum.).

Summary: The highest coefficient of linear expansion was found with board faced with phenolic resin; boards faced with paper had a lower coefficient of linear expansion than plain (unsurfaced) boards.

215. Jarvi, A. 1983. Effect of changes in moisture content on the dimensions of fiberboard. Valtion Teknillinen Tutkimuskeskus, Tutkimuksia (Tech. Res. Center of Finland, Res. Rep.) 170: 46 p. (Finn.; Engl. sum.).

Summary: As a result of different absorption rates, the differences in moisture content between boards at final equilibrium were generally smaller than after conditioning for 2 to 3 weeks. In all boards, the change in moisture content almost to equilibrium was directly proportional to the logarithm of time. Boards attained maximum linear swelling faster than final equilibrium moisture content, particularly insulating boards.

216. Klinga, L.O.; Back, E.L. 1964. Drying stresses in hardboard and the introduction of cross-linking stresses by a heat treatment. Forest Products Journal. 14(9): 425–429.

Summary: Drying stresses were rather pronounced in wet-process hardboard. Boards had permanent expansion in thickness as well as contraction in the plane of the panel. Drying stresses in the plane of the board were much smaller in S2S hardboard made by dry-pressing of insulation board that had been hot-air dried with little restraint. In a heat treatment, covalent bonds were formed in the hardboard at almost water-free conditions. This cross-linking eliminated the permanent contraction in the plane of the wet-process hardboard.

217. Kluge, Z.E.; Tsekulina, L.V. 1978. Impregnation of hardboards from sawdust with drying oils followed by thermal treatment. Tekhnol. Modif. Drev. 25–29. (Russ. sum.).

Summary: The rate of oil absorption and the amount absorbed depended on board composition

and density. Results showed that the best board quality was obtained with a content of 9 to 10 percent of the oil blend and thermal treatment at 356°F (180°C) for 3 h. Water resistance was increased 12 to 14 percent and static bending strength 1.2 x 10^6 lb/in^2 (8 MPa) over that of untreated boards.

218. Lehmann, W.F. 1972. Moisture-stability relationships in wood-base composition boards. Forest Products Journal. 22(7): 53–59.

Summary: Wood-base composition boards were used to study the relationships of physical properties to dimensional stability characteristics of the panels. All rate-related characteristics were found to be dependent on interparticle capillarity as influenced by particle orientation, particle geometry, surface areas, and density. Total moisture absorption was controlled by characteristics inherent in each panel type and was found to be a function of the logarithm of time. Linear expansion and thickness swelling were found to be directly correlated with moisture absorption and, in some cases, to time.

219. McNatt, J.D. 1973. Buckling due to linear expansion of hardboard siding. Forest Products Journal. 23(1): 37–43.

Summary: Buckling of overlapping strips or whole panels of 35 different hardboard siding products attached to lumber frames and exposed at 90 percent relative humidity for 8 weeks was not clearly related to board properties or to buckling of board specimens restrained on a steel frame, although three thinner boards that were ≤0.210 in. (0.008 mm) thick and expanded ≥0.5 percent between 30 and 90 percent relative humidity were judged unsatisfactory as whole panels. All other sidings were judged to be satisfactory.

220. Murmanis, L.; Youngquist, J.A.; Myers, G.C. 1986. Electron microscopy study of hardboards. Wood Fiber Science. 18(3): 369–375.

Summary: Electron microscopy was used to examine wet- and dry-formed aspen fiber hardboards to obtain information on the internal structure of the hardboard and on fiber–resin interactions. In wet-formed boards, the resin showed even distribution. In dry-formed boards, the resin showed uneven distribution; it was found in large accumulation in some areas, but was absent in other areas.

221. Pallini, M.A.; Hotham, C.G. 1974. Dimensional stability of hardboards. ATIPCA. 13(1): 54–57. (Span. sum.).

Summary: Tempering time beyond the minimum of 3 h did not greatly affect dimensional stability. The best dimensional stability values were obtained with hardboards formed at 90 percent relative humidity and 167°F (75°C).

222. Princes Risborough Laboratory. 1975. Factors affecting fiber building boards in service. BRE Information IS–2/75 March 1975. England. 4 p.

Summary: Moisture content is of paramount importance as every aspect of board performance is related to and regulated by the moisture contents attained in service. The equilibrium moisture content of a board varies according to the specific relative humidity and temperature conditions of the environment in which the board is used. Density does influence absorption of liquid water since lower density boards can absorb more moisture by virtue of their greater proportion of internal free-space. The lower density medium hardboards achieved equlibrium moisture content values closely similar to that of higher density boards, but absorbed disproportionate amounts of water following 24-h immersion. Dimensional changes also occurred in response to differing moisture conditions. The percentage loss of strength at the higher temperature as measured by modulus of rupture varied between 13 and 24 percent for the different brands of hardboard, while losses of up to 16 percent were recorded for modulus of elasticity (stiffness).

223. Sefain, M.Z.; Fadl, N.A.; Rakha, M. 1984. Thermal studies of hardboard impregnated with different resins. Cairo, Egypt: Research and Industry. 29(1): 39–42.

Summary: Thermal treatment of hardboard impregnated with four different resins (phenol formaldehyde, urea formaldehyde, novolac, and melamine formaldehyde) was carried out at different exposure times and temperatures. Bending strength of novolac samples was improved even at low hardening temperatures, while water resistance properties were improved in melamine samples when heated to elevated temperatures.

224. Snopkov, V.B.; Sukhaya, T.V.; Yakubovich, V.A.; Khrapova, G.I. 1986. The kinetics and mechanism of water absorption of fiberboards. Lesnoi Zhurnal 1986. (Beloruss. Tekhnol. Inst., USSR). 3: 71–76.

Summary: Water absorption took place in two periods, differing in the speed of the process. Transition from the first to the second period occurred when a critical moisture content was reached. Once this critical content had been exceeded, board strength and water resistance were irreversibly impaired.

225. Stillinger, J.R.; Currier, R.A. 1954. Relative humidity, moisture content, and dimensional stability relationships in hardboard of three manufacturers. Rep. T–7: Corvallis, OR: Forest Products Laboratory. 4 p.

Summary: Tests with 11 commercial hardboards showed (1) important differences in the amount of moisture absorption and dimensional changes cannot so far be explained, (2) the equilibrium moisture content of commercial hardboards is definitely lower than that of wood, the former being ca. 50 to 75 percent of the latter for a given relative humidity and temperature, and (3) the variations in moisture content, thickness swelling, and linear expansion with increasing relative humidities are similar for all hardboard types, as are variations in thickness swelling or linear expansion with increasing moisture content.

226. Suchsland, O.; Woodson, G.E. 1986. Fiberboard manufacturing practices in the United States: 10. Heat treatment, tempering, and humidification. Agric. Handb. 640: Washington, DC: U.S. Department of Agriculture: 168–178.

Summary: The mechanism of dimensional change is explained and the functions of heat treatment and humidification are introduced. Heat treatments reduce the water adsorption by the cell wall and improve the bond between fibers, which, in turn, helps resist the creation of voids during swelling. There is a net contraction of board dimensions as a result of heat treatment, and dimensional changes between 30 percent and 100 percent relative humidity exposure increase somewhat, but the component corresponding to the 65 percent to 100 percent relative humidity interval is reduced.

227. Suchsland, O. 1990. Linear expansion and buckling of hardboard. Wood Science Series 2. East Lansing, MI: Michigan State University: 12 p.

Summary: For hardboard siding to be competitive technically, linear expansion must be reduced and stiffness must be increased. A linear expansion <0.2 percent for the exposure interval of 50 to 90 percent relative humidity and a modulus of elasticity of at least 1 x 10^6 lb/in^2 (689 MPa) for 3/8-in.- (9.53-mm-) thick siding could be viewed as practical guidelines for product improvement.

228. Szabo, T.; Grierson, S.U. 1976. Improved method for linear expansion measurement in hardboards. Forest Products Journal. 26(1): 54–56.

Summary: A new method of measuring the linear expansion of hardboards was developed. It produces the same results as the commonly used ASTM method but requires about half the time.

229. Tsolov, V. 1985. Fiberboards with high water resistance for building. Nauchni Trudove, Mekhanichna Tekhnologiya na D'rvesinata, Vissh Lesotekhnicheski Institut, Sofiya 1985. 29: 61–64. (Bulg.; Russ.; Ger. sum.).

Summary: Soft fiberboards were made with various resins and hot- or cold-pressing. Data on bending strength, swelling, and water absorption are shown graphically.

(Also see references 22, 26, 94, 95, 101, 104, 106, and 273.)

Patents

Dry Process (230-236)

230. Abitibi Co. 1967. High density hardboard by hot-pressing paper-like sheets. Assignee: (ABIT) ABITIBI CORP, Document type: Patent, P.N.: CA 831957, I.D.: 000000 (1967).

Summary: Paper-like mats of groundwood high-lignin-content pulp are produced and dried in a papermaking machine. A stack of mats are hot-pressed to form hardboard of 50 to 70 lb/ft^3 (800 to 1,120 kg/m^3). The pulp may contain 1 to 3 percent drying oil and/or ferric sulfate catalyst 0.75 percent by dry weight of the board. Specifically, 12 to 18 mats are used for 1/8-in. (3.17-mm) board, and 20 to 28 mats for 1/4-in. (6.34-mm) board. The mats can be heated before pressing and the hardboard baked after pressing. Specifically, 1/8-in. (3.17-mm) board is pressed at 475°F to 500°F (245°C to 260°C) at 1,000 lb/in^2 (6.9 MPa) for 1 min, and 1/4-in. (6.34-mm) board is pressed at about 500°F (260°C) at 500 lb/in^2 (3.5 MPa) for 75 s.

231. Celotex. 1961. Fiber boards of reduced moisture permeability faced. Assignee: (CELT) CELT; CELOTEX Document type: Patent, P.N.: GB 1031161, I.D.: 000000 (1961).

Summary: The panel consists of a sheet of fiberboard with a sheet of paper-supported moisture-resistant plastic on one face and a similar sheet on the other face. The thickness of the plastic film must be sufficient to cause a considerable reduction in the moisture vapor permeability of the panel. Preferably, the plastic film is also resistant to any chemicals in the atmosphere in which the panel is to be used.

232. Mal'tseva, T.V.; Gamova, I.A.; El'bert, A.A.; Strelkov, V.P. 1984. Composition for production of hardboards by the dry method. Document type: Patent, P.N.: USSR pat. 1118655, I.D.: Oct. 15, 1984. Field: USSR appln. 3484593/23–05 (Aug. 5, 1982).

Summary: Water absorption and board swelling are reduced if hardboards are produced from a mixture of 4 to 5 percent condensation product of urea ethylene glycol at a molar ratio of 3:0.5 to 3:1, 1 to 2 percent paraffin, and wood fibers for the remainder.

233. Paterson, A.R. 1974. Fibre or hard-board preparation having improved dimensional stability. Assignee: (PATE/) PATERSON, A.R.: Document type: Patent, P.N.: US 3790417, I.D.: 740205.

Summary: At least one layer of a thermosetting resin is interwoven between layers of resin-impregnated cellulosic fibers to form a composite, which is cured under heat and pressure into an integral board. The thermosetting resin is selected from amino- and phenolic resins. The total amount applied to the fibers and forming the interwoven layer is 2 to 15 weight percent of the total weight of the composite. The amount of resin used in bonding the fibers is preferably <40 percent of the total weight of resin in the board.

234. Pietrareanu, I.; Plugariu, I.; Radu, H.; Sava, B.; Marinescu, I. 1987. Manufacture of fiberboard with smooth surfaces. Assignees: Combinatul pentru Industrializarea Lemnului. Document type: Patent, P.N.: Romania pat. 91174, I.D.: March 30, 1987, Field: Rom. appln. 116395 (Nov. 26, 1984).

Summary: Fiberboards with water absorbability ≤30 percent after 24 h immersion and swelling ≤18 percent after 24 h in water are manufactured from dried layers of wood fibers sprayed with 40 to 60 percent solutions of melamine urea formaldehyde resins and, optionally, phenolic resins (≤2 percent dry resin on the fibers).

235. Pulp and Paper Research Institute. 1976. Cellulosic fibre thermoplastic polymer composite hardboard—in which one or both components are subjected to corona treatment to reduce water absorption. Assignee: (PPCA) PULP & PAPER RES CA INST. Document type: Patent, P.N.: CA 1000650, I.D.: 761130.

Summary: To enhance dimensional stability of composite hardboards on exposure to water (including hot pressing a dried mixture of thermoplastic polymer and cellulosic fibres), boards are improved by subjecting the polymer and/or the fibers to a corona treatment. The composite hardboards have improved water resistance and at the same time strengths comparable to the best quality boards available commercially.

236. Strelkov, V.P., Miretskii, V. Yu.; Varshaver, E.M.; Kozodoi, L.V. 1978. Stock for the manufacture of superhard hardboards. Document type: Patent P.N.: USSR pat. 604706 I.D.: April 30, 1978. Field USSR appln. 2361472/29–15 (May 19, 1976).

Summary: Water absorption of superhard hardboard is improved if the boards are made from 83.0 to 94.7 percent wood fibers, 2 to 5 percent phenyl formaldehyde resin, 0.3 to 2 percent hexamethylenetetramine, and 3 to 10 percent of a maleic anhydride-modified petrochemical resin in a ratio of 85 to 89 percent resin and 5 to 15 percent maleic anhydride.

Wet Process (237–250)

237. Bilton, G. (Abitibi–Corporation). 1980. Method for controlling caliper and edge and corner delamination of hardboard. Assignee: Abitibi–Corporation, P.N.: US 4,168,200. I.D.: 559,387.

Summary: Wet-process hardboard can be manufactured by flowing a layer of pulp stock on a moving forming surface. By selective addition of heat-curable binding agents and further dewatering and hot pressing the mat to consolidate the mat fibers, a hardboard is formed having increased bond strength between the fibers in strip-like mid-thickness regions where the binding agent is more concentrated.

238. Biryukov, M.V. 1988. Wood fiberboard manufacture by wet-forming involves using water soluble extract from larch wood as binder to increase strength. Assignee: Wood Proc. Ind. Res., Document type: Patent, P.N.: SU 1423660, I.D.: 880915.

Summary: The method involves milling the chips into fiber; adding the binder; forming the web for hot pressing; and thermotreating and conditioning the board. This can provide increased board strength. For example, using 50 percent solution of larch wood extract provides water absorption of 21.5 percent and expansion of 8.0 percent. In addition, the proposed binder is less expensive than previously used phenol-formaldehyde resin.

239. Fujitani, J.; Ohtake, M. 1975. Water-resistant fiberboards containing saponified dodecyl vinyl ether–vinyl acetate copolymers. Assignees: Denki Kagaku Kogyo KK., Document type: Patent, P.N.: Jap. pat. Kokai 10852/75, I.D.: Feb. 4, 1975., Field: Jap. appln. 62698/73 (June 4, 1973).

Summary: Vinyl acetate copolymers containing 0.01 to 2 mole percent alkyl vinyl ether are saponified to greater than 85 mole percent. The powdered products are added to pulp slurries and made into fiberboards.

240. Hibino, H. 1968. Fibre board production using atactic polypropylene to improve water resistance and strength. Assignee: (HIB/) HIBINO H, Document type: Patent, P.N.: JP 72009270.

Summary: Small pieces of atactic polypropylene are mixed with wood chips; the amount of polypropylene is 0.5 to 2.5 percent based on dry weight of wood chips. Steam (pressure 12 kg/cm^2, 356°F to 392°F (180°C to 200°C)) is then supplied and the polypropylene is melted and adheres to the wood chips, which are then disintegrated to pulp. Water is added to prepare a suspension of pulp, and wet sheets are prepared, dehydrated, and pressed by a hot press to make fibre boards at 356°F to 392°F (180°C to 200°C) and 50 kg/cm^2 for 6 to 8 min.

241. House, C.B.; Leichti, R.J. 1983. Thermoplastic hardboard from acetylated mat. Assignees: United States Gypsum Co., Document type: Patent, P.N.: U.S. pat. 4388378, I.D.: June 14, 1983, Field: U.S. appln. 213263 (Dec. 5, 1980).

Summary: A wet-laid mat of wood fibers is acetylated by coating the mat with acetic anhydride (5 to 70 percent by volume of the mat) and heating the mat at 150°F to 300°F (66°C to 149°C) while confining all the acetic anhydride within the mat for 20 to 120 min. Acetic acid and excess anhydride are removed. The acetylated mat is pressed into hardboard, which may be bent into loops and spirals and other curvilinear shapes to make articles of furniture, packing materials, and the like.

242. Kapanchan, A.T. 1982. Composition for the manufacture of wood fiberboards. Document type: Patent, P.N.: USSR pat. 973682, I.D.: Nov. 15, 1982, Field: USSR appln. 3334505/29–12 (Sept. 30, 1981).

Summary: Mechanical strength and water resistance of boards are increased if the boards are produced from 91.97 to 97.87 percent wood pulp, 0.5 to 1.5 percent phenol formaldehyde resin, 0.5 to 1.2 percent paraffin, 0.2 to 6.0 percent precipitant, and 0.005 to 0.100 percent polyethylene oxide (molecular weight 600,000 to 6,000,000).

243. Kiseleva, G.V.; Notkin, M.M.; Samsonova, G.Z.; Kiselev, Y.I.; Lazarenko, Y.F.; Kabanov, A.I.; Volichenko E.V.; Mersov, E.D.; Strizhenko, V.V. 1989. Method of producing hardboards with refined surfaces. Field: USSR appln. 4,285,184, P.N.: USSR 1,527,354, I.D.: 4,285,184.

Summary: This method for the manufacture of hardboard includes the preparation of wood–fiber stock for the base layer and a pulp-containing stock for the refined layer, formation of the wood fiber mat, application of the refined layer during mat formation hot pressing, and heat treatment. Board quality is improved (by increasing its strength, water resistance, and decorative properties) if the refined layer contains 10 to 20 percent wastepaper pulp and if the pulp–fiber mixture used for the refined layer is treated with a cationic electrolyte (1,2-dimethyl-5-vinylpyridine methyl sulfate) in the amount of 0.01 to 0.1 weight percentage on oven-dry fibers of the refined layer.

244. Luszczak, M.M. 1980. Production of hardboard. Document type: Patent, P.N.: U.S. pat. 4227965, I.D.: Oct. 14, 1980, Field: U.S. appln. 54206 (July 2, 1979).

Summary: The process for making hardboard is modified to impart additional strength and water resistance to the board while eliminating baking after hot-pressing as well as conventional tempering steps.

245. Masonite Canada Ltd. 1969. Water absorption testing of hardboard, giving reproducible results in a short time. Assignee: (MAS–) Masonite Canada Ltd. Document type: Patent, P.N.: CA 919453.

Summary: A test sample is calipered and weighed and the rough side is then immersed in clean water at 70°F to 90°F (21°C to 32°C) while exposing the opposite side to a vacuum of 1 to 10 in. Hg (3.4 to 33.9 kPa) for ≤1 h (preferably 3 in. Hg (10.2 kPa) for 5 min). The sample is then removed to be reweighed and recalipered. This method reduces the time necessary for the control of the production process.

246. Noda, K.K. 1991. High dimensional stability acetylated fiberboard production by reacting impregnated acetic anhydride with organic fiber, adding adhesive, air-drying, and press-forming. (Japanese). Assignee: NODA KK, P.N.: JP 3130104, I.D.: 89269831(891016).

Summary: Acetylated fiberboard is prepared by acetylating hydroxyl groups in organic fiber by reacting impregnated acetic anhydride with the organic fiber, adding to the acetylated organic fiber an adhesive whose hardening is promoted in the presence of an acid, air drying the acetylated fiber, and pressure-forming the fiber into a board. The filamented wood fibers consist of 50 to 80 weight percent of acetic anhydride or chloroacetic anhydride. During the process, the fiber is heated to 158°F to 302°F (70°C to150°C). The hot-pressed board possesses high dimensional stability.

247. Nippon Hardboard Co. Ltd. 1969. Fiberboard manufacture with excellent water resistance and dimensional stability, by ionized radiation. Assignee: (NIH)NIPPON HARDBOARD CO LTD, Document type: Patent, P.N.: JP 72024260.

Summary: The wet mat is impregnated with a water-soluble synthetic vinyl resin such as polyvinyl alcohol, polyacrylic acid, or polyvinyl acetate by spraying or injection. The wet mat is then irradiated with radioactive rays to cause crosslinking on hydroxyl groups in wood fiber cells with the synthetic resin. The intermolecular bond is completed by hot-pressing the wet mat or heating in a drying furnace.

248. Pecina, H., Wienhaus, O.; Kuehne, G.; Roessler, O.; Nigrini, H. 1986. Binders for fiberboards. Assignees: Technische Universitaet Dresden. Document type: Patent, P.N.: East Ger. pat. 238766, I.D.: Sept. 3, 1986, Field: East Ger. appln. 273227 (Feb. 13, 1985).

Summary: Fiberboards are prepared with binders prepared from wood tar, formaldehyde, and, optionally, small amounts of phenols. A precondensate prepared from powdered pine tar and aqueous solution of formaldehyde is used with an aqueous pulp suspension in the manufacture of hot press-cured fiberboards having bulk density of 0.95 to 1.05, flexural strength of 5.5 to 7.5 x 10^6 lb/in^2 (38 to 52 MPa), swelling (thickness) in water of 14 to 28 percent, and water absorption of 12 to 45 percent.

249. Sukhaya, T.V. 1981. Composition for manufacture of hardboards. Document type: Patent P.N.: USSR pat. 814775, I.D.: March 23, 1981. Field: USSR appln. 2825994/29–15 (Oct. 8, 1979).

Summary: The water resistance of fiberboards is increased and the amount of petroleum products in plant effluents is reduced if the boards are manufactured from a mixture of 0.3 to 1.5 percent albumin, 0.5 to 1.55 percent crude oil-free paraffin, 0.5 to 2.0 percent of a 55-percent solution of polycondensate of dicyandiamide with formaldehyde and urotropin in alcohol solution, and fibers.

250. Tsarev, G.I., Kozachenko, A.M.; Leonovich, A.A. 1974. Hardboard manufacture. Document type: Patent, P.N.: USSR pat. 442942.

Summary: Board strength and water resistance are improved by treating the board surface after pressing with 0.5 to 6 percent (of the weight of ovendry fibers) of a polyisocyanate, followed by heat treatment at 194°F to 320°F (90°C to 160°C) for 10 to 120 min.

Dry and Wet Processes (251–254)

251. Beglyarov, E.M.; Vakhterov, G.N. 1976. Method of manufacturing finished hardboards. USSR Pat. 501897, I.D.: Feb. 5, 1976, Field: USSR appln. 2060438/30–15 (Sept. 19, 1974).

Summary: Dimensional stability of hardboards finished on one side with textured paper and wettability of the glued surfaces is improved and toxicity of the mat is decreased if the textured paper is first coated with an aqueous solution of a surfactant made from a mixture of mono- and polyalkylphenyl ethers of polyethylene glycol. The adhesive is a mixture of 1 to 30 percent urea-formaldehyde resin and 70 to 99 percent of a 0.1 percent aqueous solution of polyethylenimine.

252. Paterson, A.; Reimschuessel, A. 1974. Process for preparing fiberboard having improved dimensional stability. Assignee: Unassigned or assigned to individual. Assignee codes: 68000 Document type: Utility, A.N.: US 209461, A.D.: 711217, P.N.: US 3790417, I.D.: 740205.

Summary: The dimensional stability of fiberboard or hardboard prepared by bonding cellulosic fibers with a thermosetting or thermoplastic resin may be improved by preparing the fiber mat in a layered construction so that one or more layers of thermosetting or thermoplastic resin are applied between layers of resin-treated fiber. The resin in the layered construction is subsequently cured under heat and pressure.

253. Sanfilippo, S.G.; White, J.T. 1982. Hardboard treating composition and process for forming hardboard surfaces. Assignees: Reichhold Chemical, Inc. Document type: Patent, P.N.: U.S. pat. 4336174, I.D.: June 22, 1982, Field: U.S. appln. 151172 (May 19, 1980).

Summary: The surface properties of hardboard (e.g., smoothness, paint holdout, water resistance) are improved by treating the board-forming mat prior to pressing with a composition including a blend of water-soluble melamine formaldehyde resins, a styrene acrylic copolymer emulsion, a small amount of an amine capable of adjusting the pH of the resulting emulsion (e.g., triethylamine), and a crosslinking acid catalyst such as oxalic acid.

254. Noda Plywood Mfg. Co. 1974. Hardboard mat treated at both ends to give uniform thickness, width, and density. Assignee: (NODA) NODA PLYWOOD MFG CO., Assignee codes: Document type: Patent, P.N.: JP 74037426, I.D.: 741008 (1974).

Summary: The apparatus consists of (1) a guide plate of right-angle triangular section and rotary blades mounted over an inclined side of the plate and upper part of a screw belt over a suction box and (2) a transfer screw disposed in parallel with screen belt, guide plate, and shaft of rotary blades in a side box.

Weathering and Accelerated Aging Research

Dry Process (255–257)

255. Alston, M.J. 1988. Weathering of hardboard—some drip edge swell effects. CSR Timber Products, P.O. Box 139, Ipswich, Qld. 4305, Australia. Appita Journal. 41(2): 124–128.

Summary: Extending the presteaming period was effective in reducing "drip edge swell." Wax content was important in controlling drip edge swell. Correlations between long-term exposure testing and short-term laboratory testing revealed that no single short-term test adequately predicted long-term drip edge swell when several process factors were changed simultaneously.

256. Grozdit, G.A.; Bibal, J.N. 1983. Surface-activated wood bonding systems: Accelerated aging of coated and uncoated composite boards. Holzforschung. 37(3): 167–172.

Summary: An accelerated weathering test was conducted on bagasse fiberboards painted using different kinds of paints. Some fiberboards were surface activated and lignin bonded. Surface-activated and lignin-bonded boards performed comparably with other boards.

257. Kurtenacker, R.S. 1975. Wood-base panel products for pallet decks. Res. Pap. FPL 273. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Summary: Hardboards swelled more than plywood and veneer when subjected to extremes of humidity and heat during accelerated aging cycles. Commercial hardboard had the poorest performance. Altering the resin mix improved the boards.

Wet Process (258–268)

258. Biblis, E.J. 1989. Engineering properties of commercial hardboard siding. Part 1. Embossed panels. Forest Products Journal. 39(9): 9–13.

Summary: Significant differences were found in the majority of properties of embossed hardboard panels from six different manufacturers. After hardboards were subjected to soaking and cycling, the level of retention of several properties was higher than the retention level of other structural wood panels.

259. Chow, P.; McNatt, J.D.; Janowiak, J.J.; Gertner, G.Z. 1985. Effects of test methods and exposure conditions on lateral nail and staple resistance of wood-base panel materials. Forest Products Journal. 35(9): 13–19.

Summary: Three test methods were compared for their suitability for determining the lateral nail resistance of wood-base panel materials: ASTM D 1037 and tests from the American Plywood Association and the Forest Products Laboratory. Several types of wood-base hardboard siding were evaluated. Maximum fastener resistance value of hardboard tested in the perpendicular direction was only slightly less than that of other hardboard. Hardboard had almost the same quality of dimensional stability as plywood and was the least variable material in lateral resistance properties.

260. Chow, P.; McNatt, J.D.; Xiong, Y.L. 1987. Effects of accelerated weathering on some physical and mechanical properties of wood-based building panels. Proceedings of the 4th International conference on durability of building materials and components; Singapore: 97–103.

Summary: Five kinds of hardboard siding materials were tested. Embossed hardboard had the least water absorption after the exposure tests and the lowest thickness swelling in the 50 to 90 percent cyclic relative humidity and 24-h soaking tests. The lowest percentage reductions in modulus of rapture and modulus of elasticity values were for embossed hardboard under all exposure conditions.

261. Chow, P.; McNatt, J.D. 1989. Performance of lateral nails and staples resistance in wood composite panels during five years exposure to weather. Proceedings of the 2d Pacific timber engineering conference; University of Auckland, New Zealand: 201–204.

Summary: Five types of commercial wood-based panels that include embossed hardboard siding were tested. After exposure to different conditions, the average thickness of hardboard showed the least change.

262. Chow, P.; McNatt, J.D.; Zhao, L. 1990. Effects of outdoor weathering on withdrawal and head pull-through of nails and staples in wood based building panels. Proceedings of the 5th International conference; Brighton, United Kingdom: 259–267.

Summary: The test involved 5 years of outdoor exposure and several laboratory accelerated exposure conditions (vacuum-pressure-soak-dry, ASTM six-cycle accelerated aging, American Plywood Association six-cycle aging, and 24-h water soak). Hardboard showed good dimensional stability and the least change in average thickness and density.

263. Lehmann, W.F. 1973. Some experiences with durability of wood-based composite panels in the United States: Accelerated aging tests as related to exterior exposure. Proceedings of International Union of Forestry Research Organizations (IUFRO) conference, S.A. Madison, WI: 693–707.

Summary: In two studies of commercially produced hardboards and particleboards, the results of three accelerated aging tests were correlated with the results of 2 or 5 years of natural weathering. The three tests were the ASTM, WCAMA, and vacuum-pressure-soak-dry (VPSD) procedures, all involving cyclic wetting and ovendrying. The VPSD test was found to be least severe, but the most highly correlated to actual exposure. Of the other tests, the WCAMA aging test was generally most severe and correlated as well with actual weathering as did the ASTM aging test. The hardboards were initially better in bending stiffness than the particleboards. Also, the hardboards retained a greater proportion of their strength after 5 years of exposure to weathering. The 14 hardboard types were of widely varied property levels, yet most boards reacted similarly to the aging tests.

264. Lundgren, S.A. 1969. Wood-based products as building materials. Part I. Swedish Fiberboard Information 2.11. The Swedish Wallboard Manufacturers Association, Stockholm, Sweden. 252 p.

Summary: This bulletin lists references related to the effects of outdoor climate condition, sorption, and moisture movements on the dimensional stability and deformation of wood-based panels, which include hardboard, oil-tempered hardboard, particleboard, and plywood products made in Sweden.

265. Mark, R.C. 1974. Artificial weathering tests for factory-finished hardboard siding. Journal of Paint Technology. 46(592): 51–56.

Summary: A thermoset acrylic finish system possessed greater flexibility and greater water permeability than an alkyd-melamine system. The greater water permeability caused increased thickness swelling in some hardboard substrates. The more brittle alkyd-melamine cracked more along the bottom or drip edge.

266. McNatt, J.D.; Link, C.L. 1989. Analysis of ASTM D 1037 accelerated-aging test. Forest Products Journal. 39(10): 51–57.

Summary: A 3/8-in.- (9.53-mm-) thick hardboard lap siding was tested in this study. Results showed that (1) four cycles of accelerated aging gave essentially the same results as six cycles, (2) deleting the 20-h freezing step from the exposure cycle did not significantly affect test results, and (3) deleting the two 3-h steaming steps did significantly affect results. (However, for convenience in conducting the test, it would be advantageous to limit the exposure to simply a hot-water soak and ovendrying.) Because of residual thickness swelling, interpretation of test results can vary depending on whether calculations of bending strength and stiffness are based on initial specimen thickness or thickness after aging.

267. Neusser, H.; Zentner, M. 1970. Weathering tests with particle board and fiber boards. Holzforschung und Holzverwertung. 22(3): 50–60.

Summary: Two wet-process hardboards showed lower weather resistance than wood particleboards. However, the fine surface texture and bending strength of these hardboards give them certain advantages if used for large, square wall elements without joints.

268. River, B.H.; Gillespie, R.H.; Baker, A.J. 1981. Accelerated aging of phenolic-bonded hardboards and flakeboards. Res. Pap. FPL 393. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Summary: The test data for four hardboards, compared to flakeboards, were the least variable and gave the best fit to the model equations. Aging had little effect on properties of some types of hardboard and flakeboard.

(Also see references 52–54, 88, 186, and 187.)

Dry and Wet Processes (269–281)

269. Braus, O. 1978. Autumn meeting of SPCI fiberboard and particleboard section. Svensk Papperstidning. 81(18): 554–555.

Summary: The 1-day conference of the Swedish Pulp and Paper Engineers Association (SPCI) addressed outdoor use and aging resistance of medium-hard fiberboards, and cloudiness and hammer-mark defects in hard fiberboards.

270. Fraipont, L. 1973. Evolution of some characteristics of hardboards during one year of weathering. Station de Technologie Forestiere. Gembloux, Belgium. Centre d'Etudes des Papier, du Papier, du Carton et des Panneaux de Fibres et de Particules. Rapport d'Activite: 179–236.

(This abstract is not available.)

271. Fraipont, L. 1974. Changes in some characteristics of hardboards exposed to one year's weathering. Rapport d'Activite, Station de Technologie Forestiere, Gembloux, Belgium: 175–240.

Summary: The decrease in tensile strength perpendicular to the surface caused by weathering was less than that in bending strength or bursting strength. The losses in these three properties amounted to 15 to 85 percent, 15 to 50 percent, and 1 to 30 percent, respectively. Splitting near the surface resulted in serious loss of internal cohesion.

272. Fraipont, L. 1975. Evolution of some physical and mechanical properties of fiber hardboards during three years of exposure to weathering. Rapport d'Activite–Station de Technologie Forestiere, Gembloux, Belgium. Centre d'Etudes des Derives du Bois: 125–219.

(This abstract is not available.)

273. Fraipont, L. 1975. Modifications of physical and mechanical properties of fiberboards caused by a long-term immersion in water at 68°F (20°C) and by natural and artificial aging tests. Rapport d'Activitie Sta., 1974, Station de Technologie Forestiere, Gemblous, Belgium: 151–212 . (Fr.; Engl. sum.).

Summary: Tabulated and graphical data from water immersion, air-conditioning, outdoor exposure, and aging tests on 70 board specimens. Correlation of the results of the tests was found to be difficult.

274. Mark, R.C. 1973. Accelerated weathering tests for prefinished hardboard siding. American Chemical Society, Division of Organic Coatings Plastic Chemicals. 33(1): 12–18.

Summary: The correlation of accelerated weathering tests to actual weathering in the field has been the subject of a great amount of controversy. Nevertheless, an analysis of data secured in 11 accelerated tests showed that some data evaluate characteristics or properties well.

275. Martensson, A. 1988. Tensile behaviour of hardboard under combined mechanical and moisture loading. Wood Science and Technology. 22(2): 129–142.

Summary: Tests on tempered hardboard in tension were made to study the effect of combined mechanical and moisture loading (mechano-sorption). The tests were performed both in a conventional way (constant load during test period), and in quasi-relaxation (strain of each specimen prescribed during the test). In both cases the moisture content was varied. The mechano-sorptive effects in the studied hardboard were small under constant load. In the relaxation tests, the effect was found to be more significant. A constitutive model was suggested and quantified on the basis of test data from the constant load experiments. The model was then checked independently against the other tests and was found to give good agreement with creep-type experiments. The model showed poor agreement when checked against the relaxation-type experiments.

276. Milon, F.G.; Cutter, B.C.; Chin, P.P.S. 1992. Freezing of water in hardboard: Absence of changes in mechanical properties. Wood and Fiber Science. 24(3): 252–259.

Summary: Dry-process hardboard roofing (1/8 in. (3.2 mm)) and two species mixes of wet-process hardboard roofings (7/16 in. (11 mm)) plus (1/8-in. (3.2-mm)) dry-process standard hardboards were examined using differential thermal analysis to ascertain the maximum moisture content that exterior hardboard could attain without exhibiting significant freezing. All samples with moisture contents greater than approximately 20 percent exhibited high temperature freezing near 50°F (10°C). Mechanical strength tests performed on dry-process (4.1 and 34.3 percent moisture content) standard hardboard exposed to freeze/thaw cycling to 122°F (50°C) revealed no consistent changes in the modulus of elasticity, modulus of rupture, tensile strength parallel to surface, or internal bond strength.

277. Neusser, H.; Schall, W. 1976. Investigation of some factors influencing properties of porous, semi-hard, and hardboards with special regard to demands of the building industry. Holzforshung und Holzverwertung. 28(5): 97–114. (Ger.; Engl. sum.).

Summary: Results showed that only a few boards are suitable for more critical outdoor construction. A useful test would be residual strength after 2 h boiling and reconditioning. In addition, an 8-year exposure test on a roof was conducted.

278. Ruffin, E.F. 1960. Exterior durability of hardboard. Forest Products Journal. 10(7): 336–341.

Summary: Hardboard durability is influenced by wood species, heat treatment, fiber additives, fiber refinement, tempering process, and severity of exposure. Results of accelerated weathering and outdoor fence exposures of various types of hardboard are reported.

279. Shur, E.G.; Rubin, H. 1969. Accelerated testing of finishes for hardboard. Journal of Paint Technology. 41: 537–550.

Summary: Good correlation was found between outdoor exposure and accelerated weatherometer tests, in terms of chalking. Mechanical tests showed that the short-duration (100 to 200 h) accelerated test exposures produced great changes in the

toughness of the paint film compared to 4-1/2 months of outdoor exposure.

280. Smith, G.A.; Paxton, B.H. 1981. The effects of surface coatings on the change in properties of fiber building boards in service. Holzforschung. 35(6): 287–295.

Summary: Standard and oil-tempered hardboards were coated with a variety of finishes, then subjected to either 40 weeks or up to 8 years of natural weathering. Ten months in the weathering machine generally proved to be less effective than 3 years of natural exposure in producing deterioration. Better results were obtained by painting the smooth side of the board rather than the screen side. If medium density hardboard is adequately protected, it can perform satisfactorily in exterior siding applications.

281. Zigel'boim, S.N.; Obsedshevskii, V.S. 1988. Accelerated testing of coloured lacquer coatings on fiberboards. Derevoobrabatyvayushchaya Promyshlennost' 1988. 5: 9–11.

Summary: Accelerated aging tests were made on four different lacquers, and their glossiness and surface roughness were determined periodically. Gloss resistance to aging increased with increasing board strength. The relation between glossiness and surface roughness was almost linear.

(Also see references 100, 104, and 114.)

North American Hardboard Standards and Test Methods for Dry and Wet Processes (282–287)

282. American Hardboard Association (AHA). 1988. Basic hardboard. ANSI/AHA A135.4. American National Standard/American Hardboard Association. Palatine, IL. 5 p.

Summary: Requirements and methods of testing for physical and mechanical properties of basic hardboard panel products.

283. American Hardboard Association (AHA). 1990. Hardboard siding. ANSI/AHA A135.6. American National Standard/American Hardboard Association. Palatine, IL. 5 p.

Summary: Requirements and methods of testing for physical properties, including water absorption, thickness swelling, linear expansion, and weatherability of hardboard siding panels.

284. American Hardboard Association (AHA). 1988. Prefinished hardboard paneling. ANSI/AHA A135.5. American National Standard/American Hardboard Association. Palatine, IL. 5 p.

Summary: Requirements and methods of testing for paneling dimensions, moisture content of prefinished paneling, and paneling finishes. Methods of identifying products that conform to the standard are included.

285. American Society for Testing and Materials (ASTM). 1987. Standard definitions of terms related to wood-base fiber and particle panel materials. ASTM Designation: D 1554–86. ASTM, Philadelphia, PA.

Summary: Standardized terms pertaining to cellulosic fiberboard, hardboard, and particleboard.

286. American Society for Testing and Materials (ASTM). 1987. Standard methods of evaluating the properties of wood-base fiber and particle panel materials. ASTM D 1037. ASTM, Philadelphia, PA.

Summary: Test procedures for evaluating properties of wood-base fiber and particle materials. Part B of this standard covers only methods for testing hardboard.

287. Canadian General Standards Board. 1987. Hardboard. Canadian Standard. Can/CGSB–11.3–M87: 7 p. (Engl.; Fr. sum.).

Summary: This standard applies to panels manufactured primarily from interfelted fibers, consolidated under heat and pressure in a hot press to a minimum density of 31 lb/ft^3 (500 kg/m^3). It defines a variety of hardboard types and specifies general requirements, detailed requirements, and minimum physical properties for each type. This standard replaces CAN/CGSB–11–GP–3M (May 1976).

Author Index

Author	Reference number (year)
Johanson, F.	59 (1966)
Johns, W.E.	172 (1978)
Johnson, J.W.	173 (1956)
Kabanov, A.I.	243 (1989)
Kalina, M.	60 (1972)
Kapanchan, A.T.	242 (1982)
Karagozov, T.	12 (1983)
Kawabe, J.	17 (1973), 78 (1974), 79 (1976)
Keany, F.M.	146 (1991)
Kehr, E.	23 (1983), 208 (1989)
Kelly, M.	61 (1972)
Kelly, M.W.	137 (1984)
Kelly, P.B.	126 (1984)
Kern, J.D.	10 (1956)
Khan, M.D.	174 (1988)
Khrapova, G.	224 (1986)
Kiselev, Y.I.	243 (1989)
Kiseleva, G.V.	243 (1989)
Kitahara, K.	62 (1965), 63 (1969)
Klinga, L.O.	175 (1966), 216 (1964)
Kloot, N.H.	176 (1951)
Kluge, Z.E.	217 (1978)
Koga, T.	77 (1961)
Kozachenko, A.M.	250 (1974)
Kozodoi, L.V.	236 (1978)
Krasnova, O.M.	177 (1987)
Krechetova, S.P.	164 (1978), 165 (1982)
Krisnabamrung, W.	93 (1968)
Krzysik, A.M.	47 (1990), 48 (1990)
Kuehne, G.	248 (1986)
Kums, U.	64 (1978), 65 (1981)
Kuroki, Y.	178 (1963), 179 (1963)
Kurtenacker, R.S.	257 (1975)
Kutnevich, A.M.	169 (1976)
Kutsak, A.A.	122 (1983)
Kuzmich, N.S.	122 (1983)
Lampert, H.	180 (1967)
Laskeev, P.K.	55 (1976), 150 (1967)
Laufenberg, T.L.	4 (1986)
Laughinghouse, G.F.	137 (1984)
Law, K.N.	14 (1975), 66 (1974), 67 (1975)
Lee, P.	127 (1988)
Lehmann, W.F.	218 (1972), 263 (1973)
Leichiti, R.J.	241 (1983)
Leonovich, A.A.	250 (1974)
Lielpeteris, U.Y.	151 (1975), 152 (1977), 153 (1978)
Link, C.L.	266 (1989)
Lipsev, N.V.	68 (1981), 168 (1979)
Listvin, A.V.	153 (1978)
Losifov, N.	214 (1980)
Luck, A.J.	125 (1981), 128 (1979), 129 (1981)
Lundgren, S.A.	181 (1958), 264 (1969)
Luszczak, M.M.	244 (1980)
Maloney, T.M.	5 (1977)
Maltseva, T.V.	138 (1981), 232 (1984)
Marinescu, I.	234 (1987)
Mark, R.C.	265 (1974), 274 (1973)
Martensson, A.	69 (1988)
Martincek, G.	70 (1972)
Masonite Canada Ltd.	245 (1969)
Mataki, Y.	17 (1973), 94 (1985)
Matysek, V.	90 (1978)
McCallum, J.M.	95 (1982)
McCollum, M.P.	15 (1986)
McMillin, C.W.	16 (1968), 26 (1983), 42 (1986), 43 (1987), 115 (1985)
McNatt, J.D.	54 (1985), 96 (1970), 97 (1974), 98 (1980), 99 (1983), 104 (1985), 219 (1973), 259 (1985), 260 (1987), 261 (1989), 262 (1990), 266 (1989)
Mersov, E.D.	243 (1989)
Miexzyslaw, T.	124 (1989)
Millet, M.A.	182 (1948)
Milon, F.G.	276 (1992)
Miretskii, V.Y.	236 (1978)
Moriyama, M.	7 (1975), 9 (1979), 142 (1976)
Morschauser, C.R.	136 (1955)
Morze, Z.	100 (1979)
Moslemi, A.A.	101 (1964), 102 (1964), 103 (1967), 114 (1973)
Muehl, J.	48 (1990)
Murmanis, L.	220 (1986)
Myers, G.C.	35 (1978), 36 (1983), 53 (1985), 104 (1985), 105 (1986), 106 (1986), 139 (1977), 140 (1987), 183 (1982), 220 (1986)
Naidu, M.V.	71 (1976)
Nam, Z.	72 (1979)
Narayanamurti, D.	73 (1969)
Nearn, W.T.	6 (1968)
Nelson, N.D.	37 (1973)
Neusser, H.	267 (1970), 277 (1976)
Nigrini, H.	248 (1986)
Nippon Hardboard Company	247 (1969)
Nixon, G.D.	13 (1956)
Noack, D.	86 (1978), 107 (1984)
Noda, K.K.	246 (1991)
Noda Plywood Company	254 (1974)
Notkin, M.M.	243 (1989)
Norberg, K.G.	74 (1968), 75 (1969)
Obsedshevskii, V.S.	281 (1988)
Oertel, J.	108 (1968), 109 (1968)
Ogland, M.J.	76 (1951), 184 (1948)
Ohtake, M.	239 (1975)
Okonov, Z.V.	141 (1973)
Osawa, K.M.	7 (1975), 9 (1979), 142 (1976)
Ostman, B.	25 (1958), 50 (1983)
Ota, M.	17 (1973), 77 (1961), 78 (1974), 79 (1976)
Ozarska-Bergandy, B.	110 (1985)
Ozolinya, I.D.	143 (1984)
Pallini, M.A.	221 (1974)
Palms, J.	80 (1979)
Panyukov, A.E.	133 (1973)
Papier und Kunstoff	186 (1971)
Paterson, A.R.	233 (1974), 252 (1974)
Pawlicki, J.	185 (1985)
Paxton, B.H.	280 (1981)
Pecina, H.	38 (1991), 187 (1981), 248 (1986)
Pel'nya, K.S.	152 (1977)
Perepelkin, K.E.	55 (1976)
Perkitny, J.	81 (1966)
Perkitny, T.	81 (1966)
Perng, W.T.	62 (1965), 63 (1969)

Author	Reference number (year)
Petermann, E.	119 (1975)
Pierce, D.S.	33 (1973)
Pietrareanu, H.	234 (1987)
Plugariu, I.	234 (1987)
Po, Z.Y.	189 (1981)
Polley, C.W.	41 (1974)
Princes Risborough Laboratory	222 (1975)
Proksch, E.	190 (1980), 191 (1976), 192 (1976)
Proson, M.	197 (1977)
Pulp and Paper Research Institute	235 (1976)
Puparinen, L.I.	188 (1977)
Puzyrev, S.A.	164 (1978), 165 (1982)
Radu, H.	234 (1987)
Raichuk, F.Z.	167 (1984)
Rakha, M.	162 (1984), 223 (1984)
Ramaker, T.J.	111 (1972), 116 (1976), 117 (1978)
Redmond, M.R.	29 (1981)
Reimschuessel, A.	252 (1974)
Richardson, G.	51 (1983)
River, B.H.	268 (1981)
Rodd, P.D.	91 (1985)
Roessler, O.	248 (1986)
Ross, N.	47 (1990)
Roth, W.	107 (1984)
Rowell, J.S.	145 (1988)
Rowell, R.M.	47 (1990), 144 (1987), 145 (1988), 146 (1991)
Rubin, H.	279 (1969)
Ruffin, E.F.	278 (1960)
Salmen, L.	51 (1983)
Samsonova, G.Z.	243 (1989)
Sanfilippo, S.G.	253 (1982)
Sauer, D.J.	89 (1969), 112 (1968)
Sava, B.	234 (1987)
Schall, W.	277 (1976)
Schaudy, R.	190 (1980), 191 (1976), 192 (1976)
Schwartz, S.L.	82 (1950)
Sefain, M.Z.	223 (1984)
Shafi, M.	174 (1988)
Sherwood, G.E.	80 (1979)
Shevchenko, V.S.	77 (1987)
Shur, E.G.	279 (1969)
Sinclair, G.D.	193 (1964)
Sinitski, V.I.	122 (1983)
Slais, E.	191 (1976)
Smith, G.A.	280 (1981)
Smirnov, V.N.	194 (1973)
Smulski, S.J.	39 (1987), 40 (1987)
Snopkov, V.N.	224 (1986)
Socha, R.P.	130 (1991)
Solechnik, N.Y.	169 (1976)
Spalt, H.A.	18 (1968)
Staton, D.	53 (1985)
Steinig, J.	119 (1975)
Steinmetz, P.E.	41 (1974), 147 (1970), 148 (1977), 195 (1968), 196 (1971)
Stemberger, A.	197 (1977)
Stern, R.K.	8 (1979)
Stillinger, J.R.	113 (1956), 225 (1954)
Strelkov, V.P.	232 (1984), 236 (1978)
Strizhenko, V.V.	243 (1989)
Suchsland, O.	26 (1983), 42 (1986), 43 (1987), 115 (1985), 198 (1965), 226 (1986), 227 (1990)
Sudo, K.	194 (1979)
Sukhaya, T.V.	200 (1988), 224 (1986), 249 (1981)
Superfesky, M.J.	99 (1983), 116 (1976), 117 (1978)
Sutton, R. F.	18 (1968)
Sutula, P.R.	114 (1973)
Sutyagina, S.E.	167 (1984)
Suzuki, H.	149 (1976)
Suzuki, M.	44 (1986)
Synowiec, J.	100 (1979)
Szabo, T.	228 (1976)
Takahashi, H.	7 (1975), 9 (1979), 142 (1976),149 (1976)
Takamura, N.	19 (1971), 93 (1968), 201 (1968)
Talbott, J.W.	45 (1974)
Tanahashi, N.	178 (1963), 179 (1963)
Tarkow, H.	175 (1966)
Tsarev, G.I.	177 (1987), 250 (1974)
Tsekulina, L.V.	217 (1978)
Tsolov, V.	206 (1978), 229 (1985)
Tsutsumi, J.	77 (1961)
Turner, H.D.	10 (1950)
Uzlov, G.A.	177 (1987)
Vacek, J.	155 (1978)
Vakhternov, G.N.	251 (1976)
Van–Gosliqa, N.L.	83 (1990)
Varshaver, E.M.	236 (1978)
Verbesstel, J.B.	46 (1977)
Vershina, V.S.	150 (1967)
Victor, V.J.	71 (1976)
Volichenko, E.V.	243 (1989)
Walker, V.Y.	176 (1951)
Walter, W.J.	118 (1983)
Walters, C.S.	20 (1974)
Wang, W.	204 (1981)
Watkinson, P.J.	83 (1990)
Wayne, R.M.	124 (1989)
Weismann, G.	154 (1989)
Wellwood, E.W.	202 (1954)
White, J.T.	253 (1982)
Wiemann, D.	107 (1984)
Wienhaus, O.	248 (1986)
Windaus, G.E.	119 (1975)
Woo, J.K.	172 (1978)
Woodson, G.E.	11 (1977), 26 (1983), 42 (1986), 43 (1987), 115 (1985), 226 (1986)
Xin, T.	48 (1990)
Xiong, Y.L.	260 (1987)
Xu, R.	204 (1981)
Yakubovich, V.A.	224 (1986)
Yamaguchi, H.	78 (1974)
Yin, S.	204 (1981)
Youngquist, J.A.	47 (1990), 48 (1990), 54 (1985), 220 (1986)
Yukna, A.D.	49 (1970)
Zamyshlyaeva, A.M.	203 (1966)
Zentner, M.	267 (1970)
Zhang, G.S.Y.	204 (1981)
Zhao, L.	262 (1990)
Zhukova, I.P.	177 (1987)
Ziedin'sh, I.O.	49 (1970), 151 (1975), 152 (1977), 153 (1978)
Zigel'boim, S.N.	281 (1988)